Turkish Journal of Engineering
https://dergipark.org.tr/en/pub/tuje
e-ISSN 2587-1366

A Stocking Diagram for Mixed Scots Pine- Kazdağı Fir Stands of Kastamonu Region

Ferhat Kara*[1], Arif Oğuz Altunel [1]

[1] *Kastamonu University, Faculty of Forestry, Department of Forest Engineering, Türkiye,* fkara@kastamonu.edu.tr; , aoaltunel@kastamonu.edu.tr

Cite this study: Kara, F. & Altunel A.O (2025). A Stocking Diagram for Mixed Pine-Fir Stands of Kastamonu Region. Turkish Journal of Engineering, 9 (1), 87-94.

https://doi.org/10.31127/tuje. 1511251

Keywords
Abies
Absolute density
Pinus
Relative density
Silviculture

Research Article

Received:5.07.2024
Revised:6.08.2024
Accepted:21.08.2024
Published:20.01.2025

check for updates

Abstract

Forest stand density diagrams help forest managers and practitioners more effectively manage stand density and tree occupancy to meet specific silvicultural goals. Therefore, creating such auxiliary silvicultural tools for different stands is essential. To our knowledge, no relative density graphs or diagrams have been developed for mixed stands in Türkiye. This study aimed to develop a stocking diagram for mixed Scots pine (*Pinus sylvestris* L.)-Kazdağı fir (*Abies nordmanniana* subsp. *equi-trojani*) stands. In the study, statistical relations between stocking percent and diameter increment in selected sample plots were also determined, and these statistical relations were compared with the "stand basal area-diameter increment relations" in the same sample plots. Stand stocking percent was found to be more descriptive than absolute density measurement units (i.e., basal area) in defining stand density in mixed Scots pine-Kazdağı fir stands. The resulting stock diagram may allow more effective use of stand growing space to achieve various silvicultural goals, including regeneration, thinning, and wildlife protection in mixed Scots pine- Kazdağı fir stands. Depicting various density measures including basal area, trees per ha, and stand stocking percent, the findings of this study would facilitate the tree density management in mixed Scots pine- Kazdağı fir stands.

1. Introduction

Mixed stands have several advantages over pure ones [1]. The mixture of trees in stands generally makes the stands more durable and resistant to wind, drought, insects, diseases, and frost [2]. These forests may also provide richer habitats for wildlife. The stands with mixture are often preferred over pure ones for recreational and aesthetic purposes. Moreover, these stands improve carbon storage [3], the amount of plant nutrients in the soil [4]), biodiversity [5], ecosystem functioning [6], and stand productivity [7]. More optimal use of soil resources in mixed stands increases and stabilizes the productivity of forests. Thus, they can reduce the adverse effects of global warming [8].

Türkiye is very rich in terms of tree species diversity. Approximately 41% of the total forested area in Türkiye consists of mixed stands, which shows a substantial mixed forest area in the country. Due to the large mixed stands acreage in Türkiye, Turkish forests are considered "rich" in biodiversity [9, 10]. The tree species in this region form various mixtures and form economically [11], ecologically, and socially essential forests. Scots Pine (*Pinus sylvestris* L.) and Kazdağı Fir (*Abies nordmanniana* subsp. *equi-trojani*) are considered among the most valuable tree species in Türkiye. These species form mixed stands in large areas of their natural distribution. These species' mixtures may offer extraordinary economic and ecological richness [12].

Considering the importance and advantages of mixed stands, it has been observed that the interest of scientists and practitioners in establishing and maintaining mixed stands has recently increased [13, 14]. Therefore, the sustainability of these stands must be secured [15]. Although mixed stands are considered more advantageous than pure stands, management, and natural regeneration in mixed stands consisting of tree species exhibiting different levels of shade tolerance (e.g., Scots pine and fir) are considered more difficult than management and natural regeneration in pure stands of the same species [2]. Therefore, density-growth relationships within mixed stands should be revealed in more detail, especially for mixed stands. Due to the difficulties in the management and regeneration of mixed stands, the number of species may decrease in some mixed stands in Türkiye, and as a result, mixed stands may turn into pure ones [15]. This reveals the importance of sustainability in mixed stands.

During the establishment of forests and their successful maintenance, forest engineers are generally interested in controlling the density of individuals in a unit area [16]. For the successful management and maintenance of all forests, especially mixed ones, stand density and the growth potential of trees at varying densities must be well understood and determined. Stand density affects many variables such as increment, photosynthesis, seedling and tree quality, growth, decomposition, soil moisture, wildlife animals, and fire frequency [2, 17, 18, 19, 20]. Therefore, determining stand density accurately and in detail forms the basis of silvicultural decisions. Especially in mixed stands, if the density is not well determined and understood, silvicultural treatments may cause the trees in the stand not to respond as expected to these interventions. They may cause the ratio of the mixture in the stand to change or cause loss of the mixture. Moreover, shelter-wood methods are generally used in many forests in Türkiye, and canopy closure is mainly utilized in the treatments made using this method. Through a succession of partial cuttings, this method allows a new generation of trees to spontaneously establish itself under the shade of older trees. However, stand density measurements are used more widely and effectively in modern forestry practices worldwide than canopy closure. Since closure is a parameter that practitioners generally decide visually, and the decision on canopy closure may vary from person to person, thus it may create some disadvantages in practice [21].

Stand density is usually indicated through absolute density measures such as stand basal area (SBA) (m^2/ha), stand volume (m^3/ha), or number of trees per ha [22]. Absolute stand density is quantitative, defined by one or more physical characteristics of a stand. Another definition of stand density is relative stand density (RSD), which is a measure of a forest stand's present density (i.e., base area or stand density index) in relation to a maximum level [16]. The use of various RSDs, including stand density index and stand stocking percent, has increased considerably worldwide. RSD measurements compare absolute density to a reference and show additional information about density in the stand [23]. Previous studies have established various methods to express RSD [24]. RSD measurement units (i.e., density index and stand stocking) are considered better indicators of stand growing space than absolute stand density measurement units (i.e., SBA, volume, and number of trees/ha) [16, 25]. RSD can generally be used with various graphs and diagrams. A stand Stocking Diagram, which shows the stand's stocking percent, is one of the most frequently used silvicultural tools in forest management [16, 26]. Stocking diagrams have become one of the most preferred RSD criteria due to their simplicity and ability to provide much information about the stand.

Various RSD charts and diagrams have been developed for pure stands of many tree species worldwide, while RSD determinations for mixed stands are limited. One of the reasons for this is that mixed forest areas are scarce in many developed countries. There are few density charts and diagrams based on RSD in Türkiye. No relative density graphs or diagrams have been developed for mixed stands in Türkiye, which are rich compared to world averages. Considering the ecological and economic importance of mixed Scots pine-fir stands in Türkiye and the advantages of RSD over absolute density measures, it is thought that creating an RSD diagram for mixed Scots pine-Kazdağı fir stands is very necessary for the sustainability of these stands. It is evident that due to the disadvantages of the canopy closure and the widespread use of RSD diagrams and graphs, the mixture in mixed stands in Türkiye may change. Therefore, this study aimed to create a stand stocking diagram for mixed Scots pine-Kazdağı fir stands of the Kastamonu region, northern Türkiye. Since both tree species occupy large forested acreages within Kastamonu region, and their mixtures mostly prevail in this region, Kastamonu region was selected as the research area. In the study, the statistical relations between stocking percent and diameter increment in selected sample plots were also determined, and these statistical relations were compared with the "SBA-diameter increment relations" in the same sample plots to reveal whether it is more descriptive than SBA.

2. Method

2.1. Study area

This research was carried out in mixed Scots pine-Kazdağı fir stands within the borders of the Kastamonu Regional Directorate of Forestry. The study area is located within the natural distribution range of mixed Scots pine-Kazdağı fir stands. The first step in creating stand density diagrams is determining the average maximum density (AMD) values in normal stands. AMD represents maximum level of competition among trees [23]. What is meant by a normal stand is that existing trees occupy the entire growing area of the stand. In these stands, stand density usually fluctuates around an equilibrium level at which additional growth is balanced by mortality elsewhere in the stand [16].

First, it should be noted that previous studies in the literature have determined that the effect of stand age, habitat conditions, and site quality on the AMD degree of the stand is not statistically significant [25]. Therefore, it will not matter in which location, elevation, aspect, etc., the mixed Scots pine-Kazdağı fir stands where measurements were made in this study [25]. However, care was taken to take the sample plots in this study in regions where these mixed stands naturally spread to represent their natural distribution area.

2.2. Study design

It should be noted that common approaches and methods which were well-accepted in the literature were followed during the creation of the stocking diagram. Measurements made in sample plots of different sizes in mixed Scots pine-Kazdağı fir stands were used to determine the AMD. It has been defined in previous studies that the number of plots used to determine the " AMD varies between 200 and 400 [26, 27, 28]. A total of 502 sample plots data were used in this study.

Approximately 100 of these sample plots were measured during field studies, and other sample plot data were obtained from the General Directorate of Forestry database. Although the plots were randomly installed in the field, and selected from the database, special care was given to distribute the plots across the natural range of the mixed Scots pine- Kazdağı fir stands. The data of the plots from which the data used to create the stock diagram were obtained are shown in Table 1.

The study aimed to select the plots to determine the AMD values required to create the stand stocking diagram from highly dense stands. In addition, care was taken to ensure that the Scots pine-fir ratio in the trial areas was at least 90% regarding SBA.

2.3. Measurements and calculation

In the plots in the mixed Scots pine-Kazdağı fir stands, the diameter at breast height (dbh) of all trees larger than 7.9 cm in dbh was measured with a caliper and recorded. Tree diameter values and species information are given in plots from the Directorate's database. Using the diameter values of the trees in the sample plots, the SBA of the plots was calculated (equation 1), and each basal area value was converted into hectares for unit area SBA calculation.

$$SBA = \sum((dbh_i^{\,2})\ (0.00007854)) \quad \text{(eq. 1)}$$

where dbh_i is the diameter at breast height of the *ith*. The number of trees measured in the plots was also converted into hectares. The quadratic mean diameter (QMD) value was also calculated for each plot (equation 2). QMD is a central tendency measure that is thought to be more suitable than the arithmetic mean for defining a set of measured trees [29]. Since trees with large diameters have a greater impact on stand density (for example, in terms of SBA), QMD should be used instead of average diameter in density calculations [29].

$$QMD = \sqrt{(\frac{\sum(dbh_i^{\,2})}{N}} \quad \text{(eq. 2)}$$

where N refers to the number of trees in the plot.

Table 1. Descriptive statistics for the sample plots. SD is the standard deviation.

Variables	Min.	Max.	Mean	SD
SBA (m^2 / ha)	9.63	88.79	41.5	14.4
Number of trees (ha)	150	2033	770	315
QMD (cm)	13.76	58.34	27.01	5.55

As mentioned above, the AMD values of stock diagrams can be obtained by measurements made in fully stocked stands. Therefore, only the fully dense sample plots were used to determine the AMD values. The following steps were followed to determine fully stocked plots. First of all, the "stand density index" (SDI) was calculated for each plot. Reineke's formula [24] was used in this calculation (equation 3).

$$SDI = (N)(QMD/10)^{1.605} \quad \text{(eq. 3)}$$

Then, each plot's relative stand density (RSD) was determined, as described by Solomon and Zhang [27]. The RSD value of a plot is calculated by dividing the SDI value of the relevant plot (SDI_D) by the maximum SDI (SDI_{MAX}) among all plots (equation 4).

$$RSD = SDI_D/SDI_{MAX} \quad \text{(eq. 4)}$$

Solomon and Zhang [27] recommend that sample plots with RSD values greater than 0.7 should be considered fully stocked. Previous studies have stated that natural stem exclusion generally occurs at RSD values of 0.7 and above [29]. Among all the measured sample plots, those with an RSD of 0.7 and above were selected, and AMD values were calculated using these plots. In previous studies, the number of fully stocked plots used to calculate AMD varied between 9 and 115 (average 26) [23, 25, 28]. This study determined that the RSD value of 55 plots was more significant than 0.7. The relevant plots are given in Table 2.

After determining the fully stocked plots, the following steps were followed to determine the AMD values. First, the relationship between the number of trees per hectare and QMD values of the 55 selected fully stocked plots was examined [23, 25]. Reineke [21] stated that the relationship between these two parameters is linear on a logarithmic scale (equation 5). Therefore, this relationship was taken as the basis in previous RSD studies.

$$Log(N) = b_{0+}\, b_1\, (logQMD) \quad \text{(eq. 5)}$$

where b_0 and b_1 values are regression coefficients. The b_0 and b_1 coefficients were calculated using fully stocked plots with the help of equation 5. The Reduced Major Axis Regression method used in previous studies was selected [14, 24, 29]. After calculating the regression coefficients, AMD (i.e., number of trees/ha) values were calculated for each 10 cm diameter class between 10 and 55 cm, again with the help of equation 5. Then, SBA for each 10 cm diameter class was calculated using equation 1.

Finally, using all values obtained for all diameter classes between 10 and 70 cm, the AMD (i.e., 100% stand stocking) curve was obtained and drawn on the diagram with the help of the SigmaPlot program [30]. Stand stocking levels below 100% were determined as a proportion of the AMD (using N and SBA values with the same QMD). For example, for the 15 cm diameter class, at 100% stand stock, SBA is 25 m^2/ha and N is 900 trees/ ha. By multiplying these SBA and N values by 0.9, SBA and N values in 90% stand stocking were calculated for the 15 cm diameter class. In this way, all stocking percent curves were obtained up to 20% stand stocking.

2.4. Comparison of relative density with absolute measures

As mentioned above, it has been stated that RSD metrics usually give better results than absolute measures in expressing a stand's growing space [31, 32]. To determine whether this situation is also valid for the stocking diagram created for Scots pine-Kazdağı fir stands, the following steps were followed;

- 30 of the sample plots measured in the study were selected. We made sure that these plots had not been treated for at least ten years.
- Increment cores were taken from the all trees in these sample plots with the help of an increment borer at breast height (i.e., 1,3 m from ground), and then the diameter increment for the last ten years was determined.
- These 10-year increments were subtracted from the current diameters (without bark) and the diameters of the trees ten years ago in the plots were calculated. The increment data combined both species.
- SBA and QMD values from 10 years ago were determined for each plot. Additionally, the created stocking diagram calculated the standard stocking percent of the plots.

Two density measures (i.e., percent stocking and SBA) were compared for predicting diameter growth based on standardized regression coefficient predictors (betas); a larger absolute beta value means a larger impact on the prediction [33]. A mixed-effect regression model was used in this analysis. In this model, diameter growth was selected as the dependent variable, SBA and stock percentage were chosen as independent variables (fixed-effect variables), and the plots were selected as the random effect variable [34]. Standardization is a method that facilitates interpretation when comparing the effects of different variables across different units within a sample [34]. Standardization was completed, and the coefficients were standardized using the "standardize" function in the R programming language [35]. While these standardized coefficient estimates represent the increase in the standard deviation of the dependent variable with a one-unit increase in the standard deviation of the independent variable [36], unstandardized coefficients represent the change in the dependent variable when the independent variable is changed by one unit [33]. The comparison is between changes in standard deviations; the greater the beta, the more the independent variable contributes to the prediction of the dependent variable [33].

3. Results and Discussion

Data for sample plots selected as fully stocked (i.e., RSD value greater than 0.7) are given in Table 2. While the SBA varies between 55 and 89 m² / ha in fully stocked sample plots, the number of trees per ha of these plots is between 533 and 2033. The QMD value in the relevant plots varied between 18 and 43 cm (Table 2).

Table 2. Descriptive statistics about the selected fully stocked sample plots. SD is the standard deviation.

Variables	Min.	Max.	Mean	SD
SBA (m² / ha)	55.67	88.79	66.67	6.83
Number of trees (ha)	533	2033	1175	330
QMD (cm)	18.83	42.54	27.79	4.91

The relationship between the number of trees per hectare and QMD is linear on a log-log scale (Figure 1). The slope of the 100% stand stocking level by OLS regression (-1.59) was determined to be very close to Reineke's universal slope of -1.605 [24].

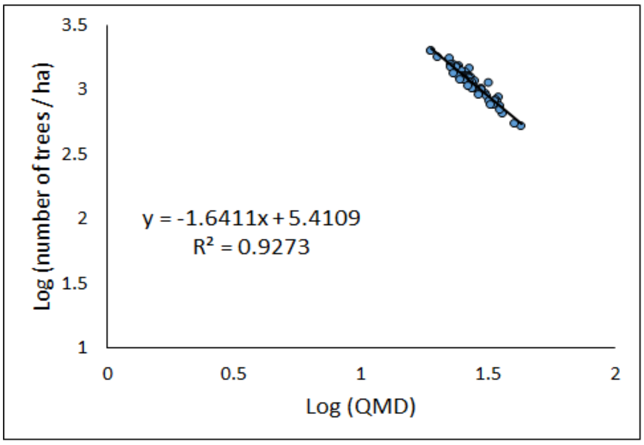

Figure 1. Relationship between the number of trees and QMD in fully stocked plots on a log-log scale

The stocking diagram created for mixed Scots pine-Kazdağı fir stands is shown in Figure 2. The diagram graphically shows the relationships between the variables of stand stocking, QMD (cm), N, and SBA (m² / ha). The stocking diagram combines absolute density (i.e., SBA and number of trees per ha) and relative density (i.e., percent stocking) in a single graph. Using any two variables among these variables makes it possible to obtain the value of a third variable for a mixed Scots pine-Kazdağı fir stand. For example, suppose the average diameter of a mixed Scots pine-Kazdağı fir stand is 25 cm and the number of individuals per hectare is 800. In that case, it is easily determined that the stocking percent of this stand is 60%, and the SBA is approximately 38 m² / ha. To give another example, in a stand with an average diameter of 20 cm and the number of trees per hectare of 1000, the stocking percent is approximately 54% (Figure 2).

On the stocking diagram created for mixed Scots pine-Kazdağı fir stands, the 100% stocking level covers the QMD range of 15 to 55 cm. The 100% stocking level in the diagram varies between 54-85 m² / ha SBA, depending on the QMD (Figure 2).

The AMD line represents 100% stand stocking. This means that the stand's growing space occupancy or density is 100%. It is accepted that trees in stands at this density level have minimum growing space and can barely survive. Gingrich [25] stated that stands exceeding the 100% stock level are considered overstock, and as tree mortality occurs due to growth and density in these stands, the stands tend towards the 100% stock level. In stock diagrams, stocking levels between 100% and approximately 30% are considered full-stocking. In other words, trees are assumed to occupy the entire growing area in this range.

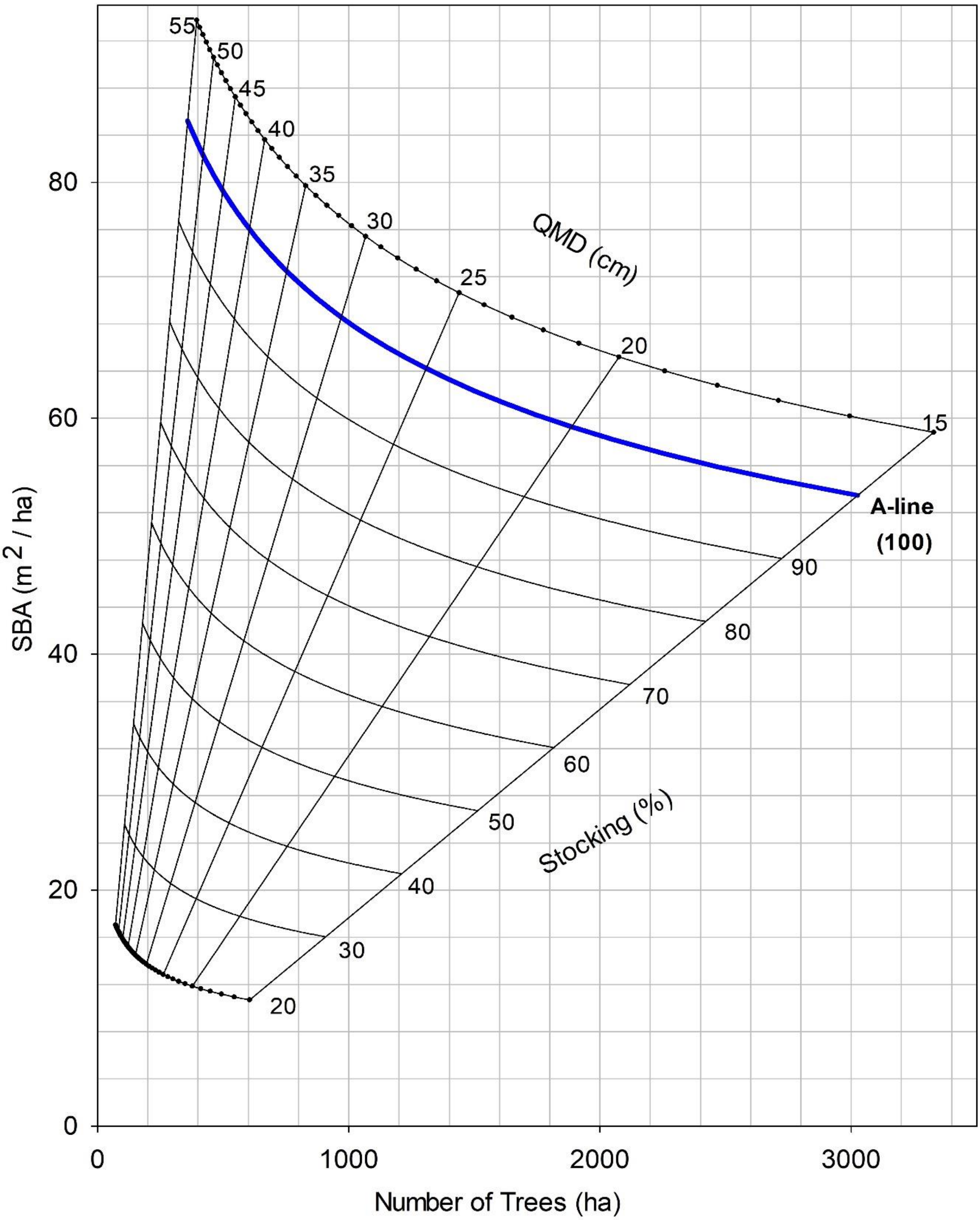

Figure 2. Stocking diagram created for mixed Scots pine-Kazdağı fir stands

As stated before, it has been noted that relative density measures (i.e., stand stocking) are considered better indicators of representing growing space in the stand than absolute stand density measures (i.e., SBA, volume, and number of trees/ha). This is likely because the trees' growing area (or occupation area) at a given absolute density (e.g., SBA) in a stand may vary depending on the average diameter of the stand. To exemplify this on the Scots pine-Kazdağı fir stock diagram, let's consider two stands with the same density in terms of SBA, let the SBA of these two stands be 40 m^2 / ha, and assume that the average diameter is 30 cm in one of the relevant stands (stand A) and 20 cm in the other (stand B). Since these two stands are the same in terms of SBA, the practitioner or land manager may tend to make the same intervention in these two stands in thinning or other silvicultural interventions. However, when we evaluate the density of these two stands in terms of stocking percent, we can determine that the stocking percentage of stand A is 58% and stand B's is 68% (Figure 2). Therefore, these stands may differ due to the different stocking levels (i.e., relative density) between Stand A and B, growth and mortality rates, cone yield, microclimatic conditions, litter decomposition, etc. In other words, the intensity of silvicultural interventions to be made to these two stands may not be the same and may differ.

When the results of comparing SBA and stand stocking in terms of representing the growing space were analyzed, it was determined that the stocking percent is a better indicator than SBA for representing the diameter increment in mixed Scots pine-Kazdağı fir stands in the Kastamonu region (Table 3)."

Table 3. Descriptive statistics about the selected fully stocked sample plots. SD is the standard deviation.

Models	SD	p-value	beta
Increment=2.819–SBAx 0.026	0.001	<0.001	0.94
Increment =3.213–Stoking x 0.0246	0.0007	<0.001	0.97

The tree size-stand density relationship is one of the most critical components of stand structure. Appropriately identifying size-frequency relationships is essential for silvicultural interventions, growth and increment models, and carbon budgets [37]. Absolute density measurements, such as SBA and number of trees per hectare, are commonly used when allocating growing space for trees in a stand. However, it is stated that the growing space for a particular SBA or number of trees varies depending on the average tree diameter [25, 38]. Stands with larger mean tree diameters represent a lower percentage of stocking at a given SBA than stands with smaller mean tree diameters [25]. Therefore, relative density measurements such as stocking percentage may offer higher precision in growing space allocation than SBA, number of trees per hectare, and volume.

The growth and yield of Scots pine and Kazdağı fir juveniles in the following years is related to the gradual reduction in stand density [2]. Since the diameter increase of trees of these species is also associated with stand density [39], it would be helpful to use the stocking percent in these mixed stands. In addition to determining the density of the stand, the stocking diagram also provides insight into the current and changing stand structure of the stand while estimating growth or when harvesting. For example, in a stand with a certain number of individuals per hectare and average diameter, how many individuals need to be cut to bring the density to the desired level can be easily determined on the diagram.

Vacchiano et al. [40] stated that natural stem exclusion begins at approximately 65% stock levels in stocking diagrams. In other words, when the stand stock reaches these levels, a reduction can be made in the stand density through thinning, and the stand density can be easily controlled from appropriate density ranges by using the stock diagram. In addition to stand stocking diagrams, different tools reveal relative stand density. One of these is "Density Management Diagrams" (DMD). However, unlike stocking diagrams, DMDs do not specify SBA. For this reason, the lack of SBA, one of the most commonly used stand density measurements in forestry, can be considered one of the disadvantages of DMDs [41]. If a DMD is available for a particular species, the purpose of stock diagrams is not to replace the DMDs but to complement them [40].

As stated above, the effect of habitat characteristics, location, and site quality on tree size-density relationships is non-existent or negligible [25, 42]. Therefore, using equations developed using the data set collected outside Kastamonu may not hinder the applicability of the diagram for mixed Scots pine-Kazdağı fir stands in Türkiye. The stocking diagram created in this study may be used in all relevant stands throughout its natural distribution area. However, it should be noted that potential measurement errors were possible, and data from the database may be subject to errors, which may make the reliability of the diagram arguable for some managers and decision-makers.

4. Conclusion

Due to its ease of use, this diagram will be a useful tool for making silvicultural interventions within the natural distribution areas of mixed Scots pine-Kazdağı stands. The diagram can be used to determine a stand's average growing space based on two of three measurements: SBA, number of trees per hectare, and average tree diameter. As a result, growing space (i.e., space occupied by trees) can be successfully used to more effectively achieve specific silvicultural goals, including regeneration, wood production, thinning, and wildlife purposes.

The situations where stock diagrams are used most effectively are in intermediate interventions. The target stand condition and the highest and lowest stand stocking limits are required to plan a thinning intervention using stocking diagrams. The highest and lowest stand stocking limits should be used to maintain full-site occupancy while avoiding density-related mortality. While the upper high limit is determined as 65-70% stand stocking, where density-related mortality usually begins, the low limit is where full site occupancy is achieved and canopy closure occurs. Although the stand stocking level at which closure occurs varies depending on the species, it is generally accepted at 35-40% stocking levels.

In addition to thinning interventions, regeneration can be planned using stocking diagrams. In those stands, the shelter-wood method usually begins with a preparatory cut, followed by a seeding cut, a light cut, and a final removal. Therefore, when regeneration efforts are started, a density reduction to below 35-40% stock levels can be considered, as the aim is to fall below the full canopy closure level with preparatory cuttings.

Due to the advantages mentioned in this study, creating stocking diagrams for different tree species and different mixed stands in future research in different regions of Türkiye, which has a rich forest structure in terms of species diversity and mixture, will contribute to more successful interventions by supporting absolute density measures.

Acknowledgement

This study was supported within the scope of TÜBİTAK TOVAG 1002 projects (Project No: 123O143). We would like to thank TÜBİTAK TOVAG group for their support to the project, and the General Directorate of Forestry, and Kastamonu and Sinop Forest Regional Directorates and their staff for providing all kinds of support and opportunities during the data collection and field studies.

Author contributions

Ferhat Kara: Conceptualization, Methodology, Writing-Original draft preparation, and Editing. **Arif Oğuz Altunel:** Validation and Editing.

Conflicts of interest

The authors declare no conflicts of interest.

References

1. Pretzsch, H., Forrester, D. I., & Bauhus, J. (2017). Mixed-species forests: ecology and management. Springer Nature, Springer-Verlag GmbH, Berlin, Germany. ISBN: 978-3-662-54551-5.
2. Odabaşı, T., Calışkan, A., & Bozkuş, H. F. (2004). Silvikültür tekniği. İstanbul Üniversitesi Yayınları, İstanbul. ISBN: 975-404-702-2.
3. Mensah, S., Salako, V.K., & Seifert, T. (2020). Structural complexity and large-sized trees explain shifting species richness and carbon relationship across vegetation types. Functional Ecology, 34(8), 1731-1745.
4. Richards, A. E., Forrester, D. I., Bauhus, J., & Scherer-Lorenzen, M. (2010). The influence of mixed tree plantations on the nutrition of individual species: a review. Tree Physiol, 30, 1192–1208.
5. Pádua, C. B. V., & Chiaravalotti, R. (2012). Silviculture and biodiversity. Writings of the Dialogue (Vol. 4, pp. 68). Rio do Sul, SC: Apremavi, Brasil. ISBN: 978-85-88733-09-1.
6. Huang, Y., Chen, Y., Castro-Izaguirre, N., Baruffol, M., Brezzi, M., Lang, A., ….. & Schmid, B. (2018). Impacts of species richness on productivity in a large-scale subtropical forest experiment. Science, 362(6410), 80-83.
7. Zhang, Y., Chen, H. Y., & Reich, P. B. (2012). Forest productivity increases with evenness, species richness and trait variation: a global meta-analysis. J. Ecol., 100, 742.
8. del Río, M., Pretzsch, H., Ruíz-Peinado, R., Ampoorter, E., Annighöfer, P., Barbeito, I., Bielak, K., Brazaitis, G., Coll, L., & Drössler, L. (2017). Species interactions increase the temporal stability of community productivity in Pinus sylvestris–Fagus sylvatica mixtures across Europe. Journal of Ecology, 105(4), 1032–1043.
9. Çolak, A. H., Tokcan, M., Rotherham, I. D., & Atici, E. (2009). The amount of coarse dead wood and associated decay rates in forest reserves and managed forests, northwest Turkey. Investigación Agraria: Sistemas y Recursos Forestales, 18 (3), 350-359.
10. Göksel, Ç., & Karip, G. B. (2017). İğneada koruma alanının arazi örtüsü/arazi kullanımının zamana bağlı değişiminin Markov zincirleri ile modellenmesi. Geomatik, 2(2), 94-105.
11. Selim, S., Demir, N., & Şahin, S. O. (2022). Automatic detection of forest trees from digital surface models derived by aerial images. International Journal of Engineering and Geosciences, 7(3), 208-213.
12. Kara, F. (2022). Effects of light transmittance on growth and biomass of understory seedlings in mixed pine-beech forests. European Journal of Forest Research, 141, 1189-1200.
13. Hulvey, K. B., Hobbs, R. J., Standish, R. J., Lindenmayer, D. B., Lach, L., & Perring, M. P. (2013). Benefits of tree mixes in carbon plantings. Nature Climate Change, (10), 869-874.
14. Pretzsch, H., & Schütze, G. (2016). Effect of tree species mixing on the size structure. density. and yield of forest stands. European Journal of Forest Research, 135(1), 1-22.
15. Genç, D. M. (2020). Orman Bakımı. Beşinci baskı. Süleyman Demirel Üniversitesi, Türkiye. ISBN: 9757929301
16. Kara, F., Loewenstein, E. F., Lhotka, J. M., & Kush, J. S. (2017). A Gingrich-Style Stocking Chart for Longleaf Pine (Pinus palustris Mill.) Forests. Forest Science, 64(3), 307-315.
17. Curtis, R. O., & Rushmore, F. M. (1958). Some effects of stand density and deer browsing on reproduction in an Adirondack hardwood stand. Journal of Forestry, 56 (2), 116-121.
18. Bormann, B. T., &Gordon, J. C. (1984). Stand density effects in young red alder plantations: productivity,

photosynthate partitioning, and nitrogen fixation. Ecology, 65(2), 394-402.

19. Smith, R. J. (2009). Use and misuse of reduced major axis for line-fitting. Am. J. Phys. Anthropol., 140, 476-486.
20. Peterson, D. W., & Reich, P. B. (2001). Prescribed fire in oak savanna: fire frequency effects on stand structure and dynamics. Ecological Applications, 11(3), 914-927.
21. Akar, A., & Gökalp, E. (2018). Designing a sustainable rangeland information system for Turkey. International Journal of Engineering and Geosciences, 3(3), 87-97.
22. Johnson, P. S., Shifley, S. R., & Rogers, R. (2009). The ecology and silviculture of oaks. CABI. USA. ISBN: 9781780647081
23. Nyland, R.D. (2002). Silviculture; concepts and applications. Second Edition. Waveland Press, Inc. Long Grove, IL. ISBN: 9781478633761.
24. Reineke, L. H. (1933). Perfecting a stand-density index for even-age forests. J. Agri. Res., 46, 627- 638.
25. Gingrich, S. (1967). Measuring and Evaluating Stocking and Stand Density in Upland Hardwood Forests in the Central States. For. Sci., 13, 38–53.
26. Larsen, D. R., Dey, D. C., & Faust, T. (2010). A stocking diagram for midwestern eastern cotonwood-silver maple-American sycamore bottomland forests. North. J. Appl. For., 27, 132–139.
27. Solomon, D. S., & Zhang, L. (2002). Maximum size-density relationships for mixed softwoods in the northeastern USA. For. Ecol. Manage., 155, 163-170.
28. Comeau, P. G., M. White, G. Kerr, & S. E. Hale. (2010). Maximum density–size relationships for Sitka spruce and coastal Douglas-fir in Britain and Canada. Forestry, 83, 461-468.
29. Curtis, R. O., & Marshall, D. D. (2000). Why quadratic mean diameter?. Western Journal of Applied Forestry, 15(3), 137-139.
30. Grafiti L. L. C. (2024). SigmaPlot, a powerful and versatile scientific tool for Data analysis & visualization. https://grafiti.com/sigmaplot-detail/.
31. Shaw, J. D., & Long, J. N. (2007). A density management diagram for longleaf pine stands with application of red-cockaded woodpecker habitat. South. J. Appl. For., 31, 28:38.
32. Pretzsch, H., & P. Biber. (2005). A re-evaluation of Reineke's rule and stand density index. For. Sci., 51, 304–320.
33. Bring, J. (1994). How to standardize regression coefficients? American Statistician, 48, 209-213.
34. Hox, J. J. (2002). Multilevel analysis: techniques and applications. Lawrence Erlbaurn Associates, Inc. New Jersey, USA. 392 p. ISBN: 9780585418728.
35. R Development Core Team., 2010. R: a language and environment for statistical computing. R Foundation for Statistical Computing, Vienna, Austria.
36. Karels, T. J., Dobson, F. S., Trevino, H. S., & Skibiel, A. L. (2008). The biogeography of avian extinctions on oceanic islands. J Biogeography, 35, 1106-1111.
37. Ahmadi, K., Alavi, S. J., Tabari, K., & Aertsen, W. (2013). Non-linear height-diameter models for oriental beech (Fagus orientalis Lipsky) in the Hyrcanian forests, Iran. Biotechnol. Agron. Soc. Environ, 17, 431-440.
38. Cochran, P. H., Geist, J. M., Ckemens, D. L., Clausnitzer, R. R., & Powel, D. C. (1994). Suggested stocking levels for forest stands in northeastern Oregon and southeastern Washington. USDA Forest Service, Research Note: PNW-RN-513. 16 p.
39. Kara, F., & Lhotka, J.M. (2020). Climate and silvicultural implications in modifying stand composition in mixed fir-pine stands. Journal of Sustainable Forestry, 39(5), 511-525.
40. Vacchiano, G., Motta, R., Long, J. N., & Shaw, J. D. (2008). A density management diagram for Scots pine (Pinus sylvestris L.): A tool for assessing the forest's protective effect. Forest Ecology and Management, 255(7), 2542-2554.
41. Farnden, C. (1996). Stand density management diagrams for lodgepole pine, white spruce and interior Douglas-fir (No. BC-X-360, pp. v+-37).
42. Chisman, H. H., & Schumacher, F. X. (1940). On the tree-area ratio and certain of its applications. Journal of Forestry, 38(4), 311-317.