Pak. J. Bot., 57(2): DOI: http://dx.doi.org/10.30848/PJB2025-2(38)

OPTIMIZING STRUCTURAL PARAMETERS FOR ACCURATE PREDICTION OF HEIGHT AND DIAMETER RELATIONSHIPS IN HIMALAYAN PINE USING ARTIFICIAL INTELLIGENCE BASED NEURAL NETWORKS

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Abstract

Accurate prediction of height and diameter relationships in the context of Himalayan Pine (*Pinus wallichiana*) holds immense ecological significance. Leveraging the capabilities of Artificial Intelligence (AI) through neural network models provides a promising avenue for achieving such predictions. This study focuses on investigating the impact of structural parameters on the accuracy of AI-based neural network models designed specifically for this purpose. By identifying the optimal combination of parameters such as the number of layers, neurons per layer, and the choice of activation functions, the research aims to enhance the precision of predictions regarding the growth patterns of Himalayan Pine. The results of this study have practical implications for ecological research and conservation efforts in the Himalayan ecosystem. By optimizing the structural parameters of AI-based neural network models, researchers can achieve more accurate predictions of height and diameter relationships for Himalayan Pine. Such predictions are instrumental for informed decision-making regarding forest management, conservation strategies, and environmental sustainability.

Key words: Neural network model; Artificial Intelligence; Pine; Optimization; Neurons, Height, Diameter.

Introduction

Artificial Neural Networks (ANNs) have recently gained popularity in the field of forest biometrics. Research on neural network modeling suggests that ANNs offer superior performance compared to traditional allometric models in various contexts. The methodology's effectiveness lies in its capacity to handle problems of any scale due to its large structure, layered distribution, learning and generalization abilities, fault tolerance, and flexibility in modeling complex variables (Binoti *et al*., 2013; Holzinger *et al*., 2013). Models of the relationships between height and diameter have been created using neural network modeling approaches to forecast different stand and individual tree features, such as the distribution of height and diameter (Castano *et al*., 2013; Ozcelik *et al*., 2013). These studies evaluated the fitting precision of models using various least squares methodologies with neural network models, and the results demonstrated that neural network models provided superior precision. Due to their substantial capacity for nonlinear mapping, high accuracy, and robustness, ANN models have been applied in various aspects of forest management, particularly in predicting tree height and forest cover types. (Ashraf *et al*., 2015, Jeelani *et al*., 2022 & Vieira *et al*., 2018). In these studies, NN models out performed traditional allometric models in terms of their ability to forecast changes in the various tree and stand properties. Its strong nonlinear modeling capability without any predetermined statistical functions and the absence of any statistical assumptions for independence, normal distribution, and homoscedasticity of residuals as well as multi- collinearity among variables, as well as spatial and longitudinal autocorrelations in data, underlie the predictive ability of AI-based NN models for these trees and stand variables proposed by the previous studies.

Several studies in agriculture, plant disease detection, and plant pattern recognition have used AI-based NN models based on deep learning algorithms (Carranza *et al*., 2017, Lee *et al*., 2015 & Mohanty *et al*., 2016) where unique modeling strategy to derive predictions of some tree and stand properties has been made possible using AI-based NN models. To predict various individual tree and stand properties, certain prediction algorithms based on NN models have been developed (Ozçelik *et al*., 2018; Ozçelik *et al*., 2017). AI-based NN models have been used in the Brazilian Amazon to

estimate the distribution of diameters in cut forests, and they have shown to be a helpful tool for making decisions (Reis *et al*., 2018). Through a fuzzy inference method, the potential of NN models has been evaluated for predicting the growth in diameter and height of Eucalyptus trees. (Ercanli *et al*., 2020), compared the prediction models of nonlinear least square model with NN models and showed that the NN models resulted in the best predictive tree heights with significant improvement in various selection indices (Ercanli *et al*., 2020). These studies which include the prediction systems based on deep learning algorithms have shown significant improvements in the prediction of image processing of plant disease diagnosis and plant pattern recognition. In forest growth and yield modeling studies, there are few studies about the network models based on deep learning to predict various tree and stand variables, which are considered as significant measurements in forest inventory. Insufficient performance analysis and comparisons of the various hidden layered neural networks are present in the majority of these researches, which are based on a single hidden layer neural network. Furthermore, none of the previously employed neural network modelling methodologies has suggested ways to choose the right number of neurons for each hidden layer of a neural network in order to make accurate predictions. In addition to these studies, it is important to conduct study on development and validation of neural network models, which are classified as a subset of artificial intelligence as this new technique is likely offer an opportunity to obtain predictions that are more accurate and predictive than those produced by conventional allometric models in the field of forestry especially in conifer trees like pines which provide various goods and services in a mountainous region like Jammu & Kashmir.

The Chir Pine (Pinus roxburghii) Forest is located in a subtropical region at an altitude ranging from 1000 m to 2000 m and accounts for approximately 6.3% of the total forest area in India (NFI/FINIDA, 1999). For the scientific management of Chir pine forests, it is essential to develop models specific to individual trees or stands at the species or stand level, as these forests contribute significantly to local and national economic development. While extensive modeling work has been conducted on Chir pine to analyze and evaluate tree height and other properties, there is currently limited knowledge regarding the height-diameter relationship using ANN models for this species. Therefore, this study aims to propose optimized artificial neural network (ANN) models to describe the height-diameter relationship of Chir pine (Pinus roxburghii) in the Jammu region of India, utilizing data from various forest divisions.

Material and Methods

Pinus roxburghii (Sarg.) commonly known as chir pine is one of the most important conifers which is found in the lower Himalayan region between latitudes 26 and 36 and 71 and 93 degrees east. It spans over 6,77,813 hectares in the states of Himachal Pradesh, Jammu & Kashmir, and Uttrakhand and grows naturally between 500 and 2500 metres above sea level in India's Himalayan outer ranges and valleys, as well as on the ridges of the Shiwalik hills surrounding the Himalayas. Chir pine forests are found in subtropical areas at elevations ranging from 1000 m to 2000 m, and their standing volume represents 6.3% of the nation's total forest cover (NFI/FINDIA, 1999). It has a total area of 1,92,552 ha in Jammu and Kashmir, out of which 94 % of area is in Jammu region. It normally reaches heights of up to 30 m, a width of 2.5 m, and a cylinder-shaped clean bole of about 12 m. The study was carried out in East forest of Jammu region, UT J&K's India. 500 trees per forest division were employed in each of 150 permanent 0.75-hectare sample locations (0.5 per forest division), dendrometric data on 1500 trees were used to achieve the study's goals.

The present investigation was carried out on pure stands of Himalayan Pine East forest Circle of Jammu region, UT of Jammu and Kashmir India as distribution of Himalayan Pine is more in this circle in comparison to other circles. Primary data on variables like height and diameter at breast height (dbh) of Himalayan Pine trees across forest divisions were taken utilizing purposive multistage sampling and final units were selected via ranked set sampling procedure by means of appropriate dendrometric gadgets (Jeelani *et al*., 2016 and McIntyre *et al*., 1952). The selection of stands was subjective in order to cover wider variations and to accurately represent the tree population and micro-site of a subject stand, sample trees within each stand were selected. The measurement of wolf, repressed, bending, or twisted trees was avoided. A diameter tape was used to measure the diameter, and a Vertex III hypsometer will be used to determine the total height.

After the collection of data on dendrometric variables, various AI based NN models were fitted and cross validated on the data collected in terms of their predictive performances, as cross validation is considered an effective method of obtaining nearly unbiased estimators of prediction error. The diameter at breast height of the trees was used as explanatory variable, and artificial intelligence based neural network models were evaluated to predict and estimate the tree height. Sample plots were randomly divided into training and testing plots, for construction of neural network models. R Studio (version 4.2.2) was used to train the ANN models as per the ANN structure, including different network architecture, number of neurons and activation functions like tan, sig, etc., were used. Different combination of structural parameters of NN model like number of nodes with two hidden layers (as standard NN models are made with only two hidden layers) and the transfer functions were used to construct AI based height prediction NN models. In order to construct the NN model, the range and step size of the hidden layers with respect to transfer functions and values within a tolerable range was determined. To determine which one performed the best, appropriate cross validation approach of 80:20 ratio was adopted, apart from this fitting precision was also taken into account while determining the number of nodes in each hidden layer. Functions like sigmoid, tangent sigmoid and Rectified Linear Unit (ReLU), which happen between the hidden layers or between the input layer and hidden layer with expression of and for logistic sigmoid function and tangent sigmoid function were used for development of models. Accordingly, selection range of the number of nodes in each layer and the transfer function was set, finally best NN structure was finalized by means

of prediction error rate which will be able to capture dendrometric relationships and results in precise height estimates. Various model performance criterions used for model selection and validation were used in this study.

$$RMSE = \sqrt{\sum_{i=1}^{n}(y_i - \hat{y_i})^2 / n}$$

$$MAE = \frac{\sum_{i=1}^{n} | y_i - \hat{y}_i |}{n}$$

$$AIC = n \times \ln(RMSE) + 2k$$

where *yi*, *y^i*, *y* and k is the actual observation, predicted value, mean of observed value and number of parameters,

RMSE-Root mean square error, MAE-Mean Absolute error, AIC- Akaike information criterion.

Results

The data collected (n=1500) was divided into training (n=1200) and test set (n=300) with former used for model calibration whereas latter was used for model validation. The summary statistics of training and test dataset is presented in Table 1. The different neural network models by varying the number of neurons per layer were fitted to the training set and the final NN model is depicted in Fig. 1a. The connections between each layer and the weights on each connection are shown by the black lines, while the bias term introduced at each phase is shown by the blue lines. The bias can be compared to a linear model's intercept. Different evaluation metrics (AIC, BIC, MAE, and RMSE) for various model configurations based on the number of neurons per layer and different activation functions (Tanh, Sigmoid, ReLU) were obtained and presented in Table 2.

AIC and BIC values ranged from 59.93 to 118.25 and 73.38 to 121.08 across all the fitted models utilizing different activation functions and neuron combination, while as MAE and RMSE ranged from 3.06 to 5.96 and 6.16 to 9.40, respectively. Models with Tanh activation consistently exhibit lower AIC and BIC values as the number of neurons per layer increases. This suggests that these models are better at explaining the variance in the data while avoiding overfitting. Both MAE and RMSE decrease as the number of neurons per layer increases. This indicates that models with Tanh activation become more accurate with more complex architectures, capturing finer patterns in the data. Similar to Tanh, models with Sigmoid activation also show decreasing AIC and BIC values with an increase in the number of neurons per layer. However, the reduction is not as consistent as in Tanh models. MAE and RMSE decrease as the number of neurons per layer increases, similar to Tanh models. This suggests that Sigmoid models also benefit from increased complexity. ReLU models generally have higher AIC and BIC values compared to Tanh and Sigmoid models across most configurations. This indicates that while ReLU models fit the data well, they might be prone to overfitting. Both MAE and RMSE decrease as the number of neurons per layer increases, showing improved accuracy with more neurons. However, the decrease in MAE and RMSE is not as consistent as in Tanh and Sigmoid models.

Table 1. Descriptive statistics of training and testing data sets.

Statistic	Training (n=1200)		Testing (n=300)	
	Diameter (cm)	Height (m)	Diameter (cm)	Height (m)
Mean	68.45	26.63	65.10	24.23
Median	65.17	25.66	66.23	27.79
Kurtosis	3.77	3.01	4.15	3.02

In case of Tanh function as the number of neurons per layer increases from 5 to 50, the prediction error rate decreases. This indicates that increasing the number of neurons per layer tends to improve the accuracy of predictions for the given dataset. Smaller values of prediction error rate are achieved as the number of neurons increases, suggesting that larger networks have the potential to capture more complex patterns in the data. However, prediction error rates with the Sigmoid activation function is higher than those with the Tanh activation function as depicted in Fig. 1b. This could imply that Tanh is performing better on this dataset, given the same number of neurons. Whereas prediction error rates with ReLU are higher than the other activation functions. Graphical representation final NN plots and PER across varying number of Neuron are given in Figs. 1 and 2.

Table 2. Evaluation metrics models under various neuron combinations and activation functions.

Neurons/ Layer	Activation functions											
	Tanh				Sigmoid				ReLU			
	AIC	BIC	MA E	RMS E	AIC	BIC	MA E	RMS E	AIC	BIC	MA E	RMS E
5	103.92	109.53	4.71	8.65	110.32	114.98	5.41	9.29	118.25	121.08	5.96	9.40
10	99.14	103.68	4.54	8.31	108.69	113.38	5.39	9.10	111.47	115.23	5.89	8.80
15	93.37	101.83	4.41	8.06	103.92	109.53	5.15	8.80	108.69	113.38	5.64	8.65
20	89.59	96.98	4.2	7.82	100.47	107.01	5.01	8.65	103.92	109.53	5.51	8.40
25	84.31	93.13	4.01	7.53	96.70	104.16	4.88	8.31	99.14	103.68	5.49	8.18
30	79.43	89.18	3.82	7.25	92.92	101.31	4.736	8.06	93.37	101.83	5.25	7.95
35	74.56	85.23	3.63	6.98	89.15	98.46	4.592	7.82	89.59	96.98	5.11	7.73
40	69.68	81.28	3.44	6.70	85.37	95.61	4.448	7.57	86.81	94.13	4.96	7.50
45	64.81	77.33	3.25	6.43	81.60	92.76	4.304	7.33	80.04	90.28	4.82	7.28
50	59.93	73.38	3.06	6.16	77.82	89.91	4.16	6.97	75.26	87.43	4.68	7.05

AIC – Akaike information criteria, BIC – Bayesian information criteria, MAE – Mean absolute error, RMSE – Root mean square error

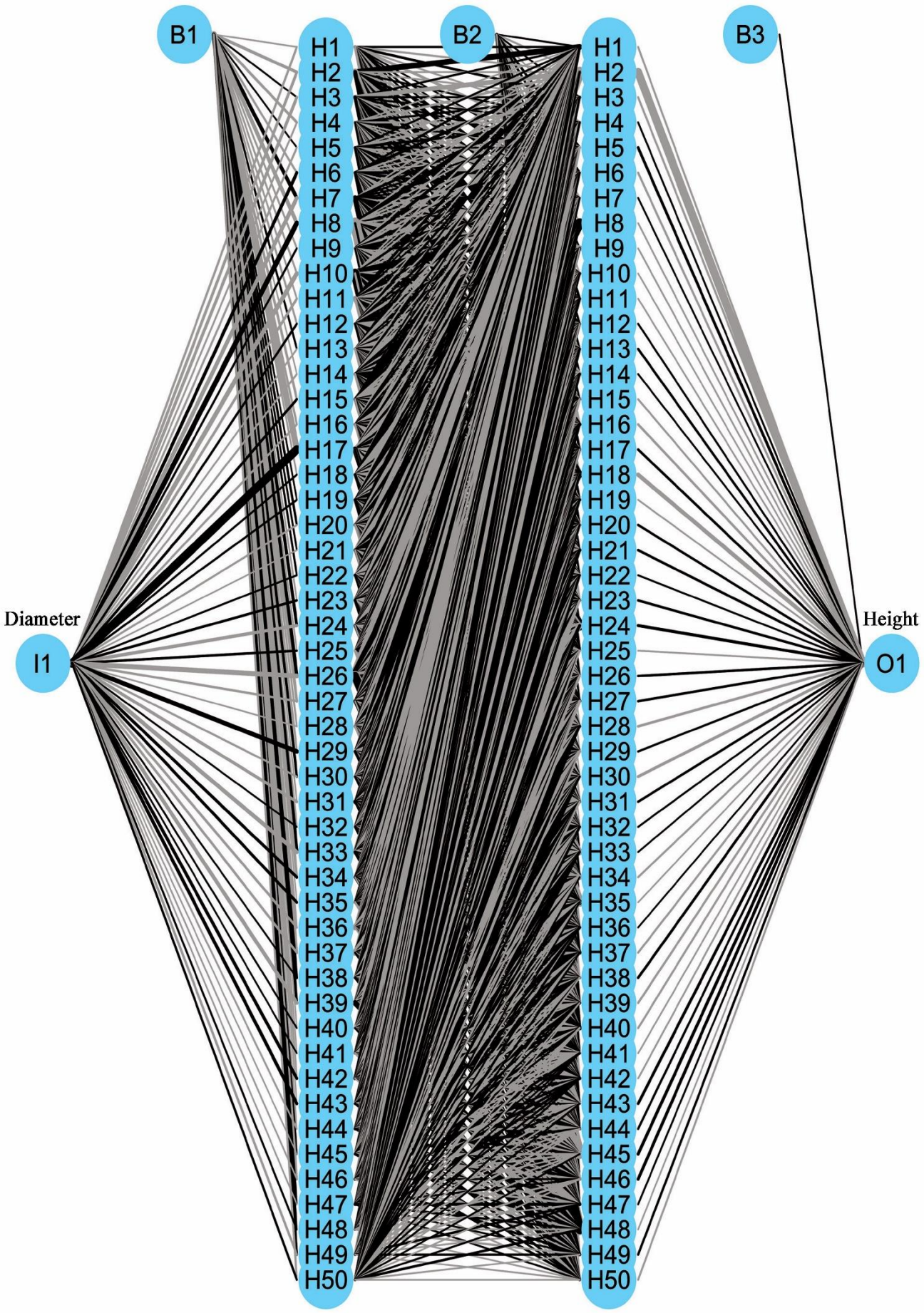

Fig. 1. NN Plot of final model with 50 neurons per layers, two hidden layers and Tanh function.

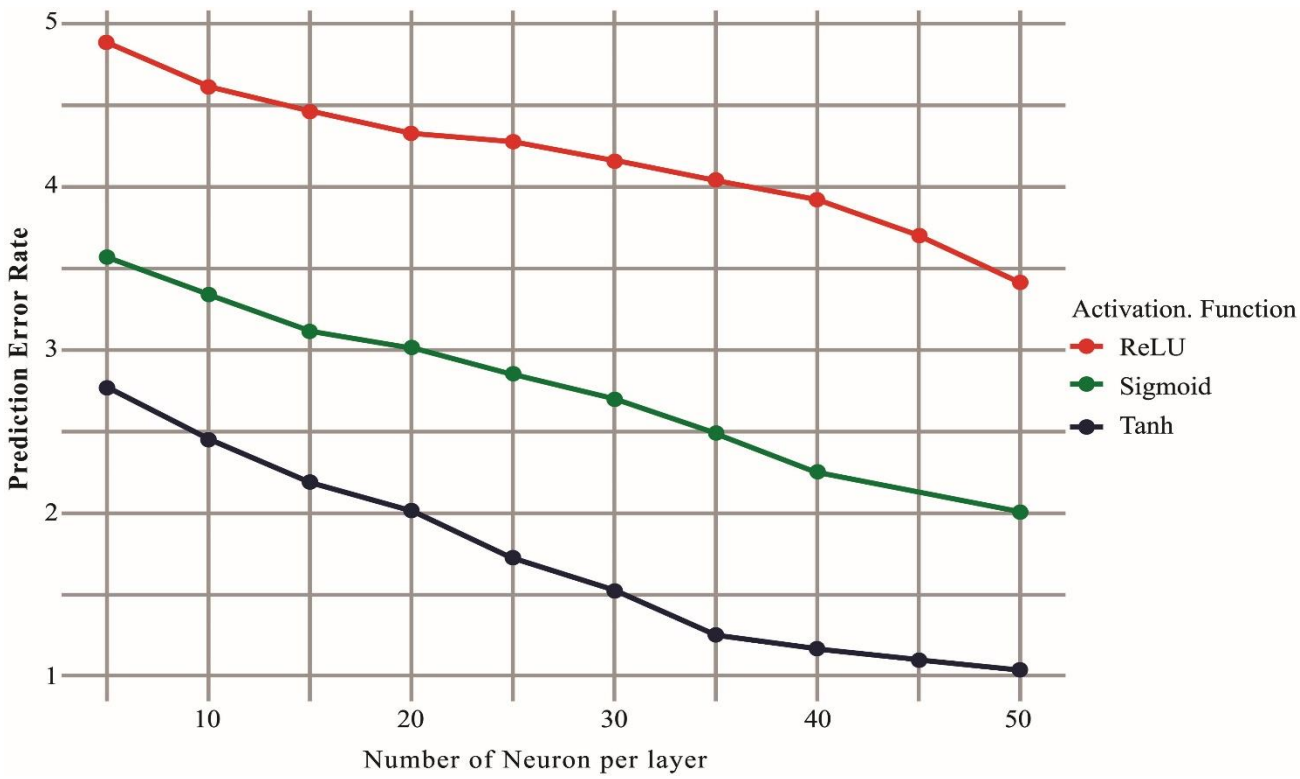

Fig. 2. Prediction error rates across neurons per layer.

Discussion

In this study, artificial neural network modelling technique has been applied to determine the relationship between diameter and height. To choose the best architecture of ANN model different alternatives for number of neurons and activations functions (Tanh, Sigmoid, ReLU) were trained and evaluated by comparing various fit statistics (AIC, BIC, MAE and RMSE). In a variety of setups, models with Tanh activation performed well in terms of AIC, BIC, MAE, and RMSE. This implies that Tanh activation is a good fit for encapsulating the dataset's variable relationships. These findings align with the research conducted by (Ercanli, 2020). Sigmoid activation also performs well, particularly with a higher number of neurons per layer. However, its performance is slightly less consistent compared to Tanh, as indicated by slightly higher AIC and BIC values. While ReLU activation can achieve good fits to the data, it appears to be more prone to overfitting, as indicated by higher AIC and BIC values, which aligns with the work done by (Ozcelik & Cao, 2018). It may require careful tuning to prevent overfitting. In general, the results suggest that increasing the number of neurons per layer tends to improve the model's predictive accuracy (lower MAE and RMSE) but may lead to overfitting (higher AIC and BIC). Balancing this trade-off is crucial when designing neural network architectures. The results under PER indicate that increasing the number of neurons per layer generally leads to improved prediction accuracy for all three activation functions (Tanh, Sigmoid, ReLU). This aligns with the idea that larger networks have the capacity to capture more intricate relationships in the data (Jeelani *et al*., 2022). The results were also in conformity with findings by (Muammer, 2020) underlining ANN models predictive ability enhances by increasing the number of neurons per layer under different activation functions. Additionally, the choice of activation function influences the performance of the network. Tanh function appears to be particularly effective in minimizing prediction errors. While more complex models might fit the training data well, they could perform worse on unseen data due to overfitting. ANNs performed well for Durango pine trees and have the potential to be used globally to a variety of species and ecological zones (Ou & Quinonez-Barraza, 2023). Ultimately, the choice of activation function and neural network architecture depends on the specific characteristics of your dataset and goals. The results provide valuable insights into how different model configurations perform, allowing you to make informed decisions about the best architecture for predicting height and diameter relationships for Himalayan Pine.

Conclusions

The neural network's architecture plays a pivotal role in determining its ability to capture intricate relationships within the data. The number of layers and neurons per layer directly influence the model's capacity to comprehend complex relationships. By strategically selecting these parameters, the model can achieve a balance between capturing nuanced patterns and avoiding overfitting. Moreover, the choice of activation functions within the neurons significantly influences the network's ability to process information effectively. To achieve the highest predictive accuracy, the study focuses on identifying the optimum combination of structural parameters. The process involves iterative experimentation to fine-tune the neural network's architecture. This not only involves exploring the effects of varying the number of layers and

neurons but also understanding how different activation functions contribute to the model's performance. Through meticulous experimentation and analysis, the study seeks to uncover the combination that yields the most accurate predictions. Furthermore, the research emphasizes the importance of comprehensive data pre-processing and the integration of domain knowledge. Proper scaling, normalization, and handling of missing values lay the foundation for accurate learning. Incorporating insights from the domain of Himalayan Pine growth patterns aids in selecting pertinent features and engineering new ones that can enhance the model's predictive capabilities. In conclusion, this research contributes to the broader understanding of AI's potential in ecological modeling. By investigating the effects of structural parameters on the accuracy of neural network models, the study advances the field's knowledge and offers a roadmap for improving predictions related to the growth dynamics of Himalayan Pine. Ultimately, these advancements have the potential to shape effective strategies for the preservation and management of this vital species and its ecosystem.

Acknowledgment

The authors extend their appreciation to Taif University, Saudi Arabia, for supporting this work through project number (TU-DSPP-2024-168).

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(Received for publication 7 March 2024)