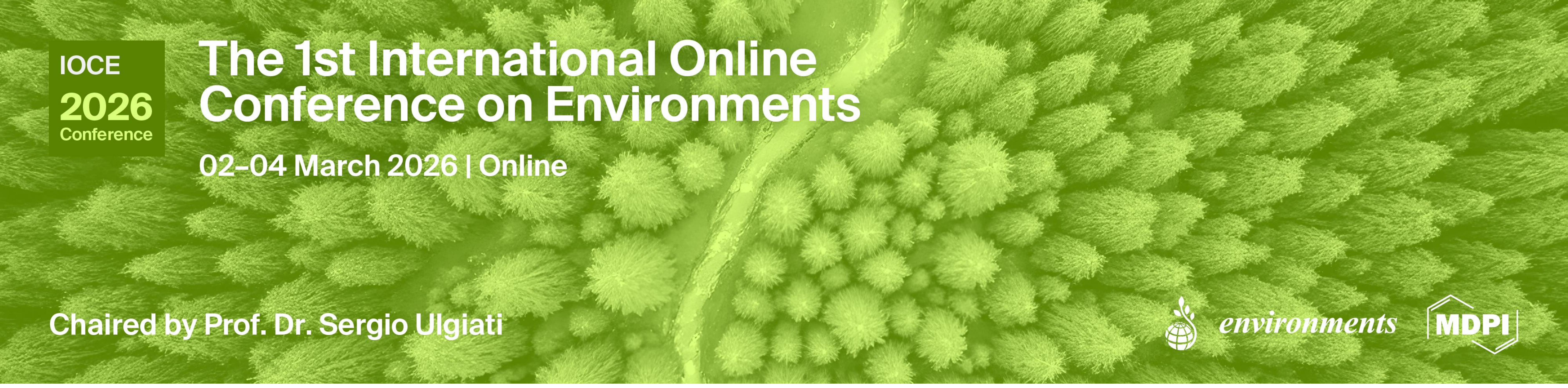

Modelling the tree height-diameter relationship of a forest species in its limit range: Alnus glutinosa (L.) Gaertn

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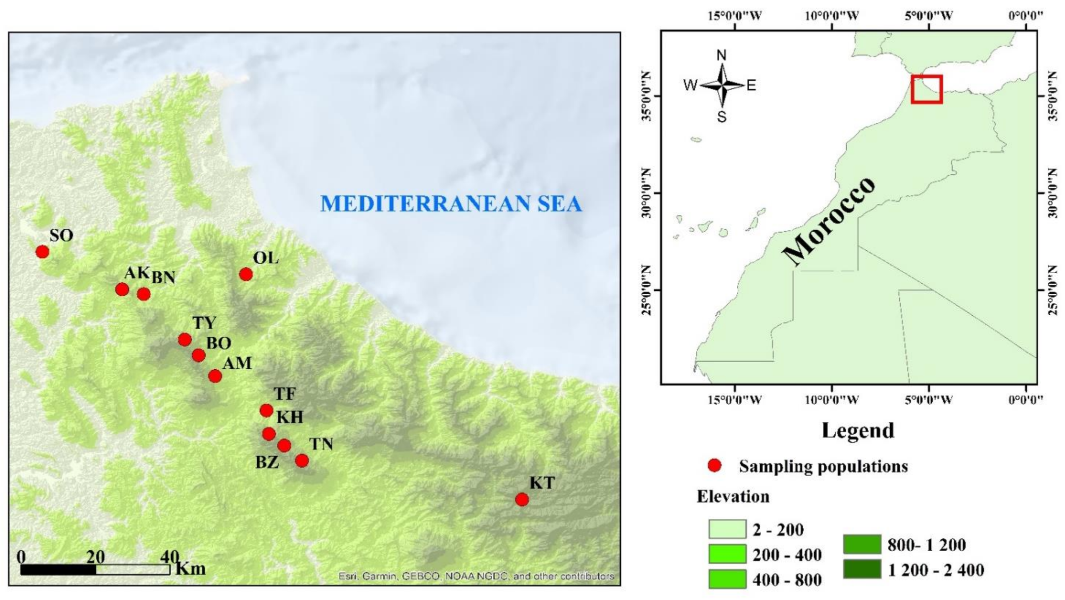
INTRODUCTION & AIM

Accurate modeling of the relationship between tree height and diameter at breast height (H–DBH) is essential for advancing forest growth prediction, monitoring, and management practices. *Alnus glutinosa* represents a keystone species in riparian ecosystems, yet species-specific H–DBH models remain unavailable. This study evaluates 37 widely cited H–DBH models to identify the most suitable predictive functions for *A. glutinosa*. Data were collected from 12 stands, with 20 randomly established 30 × 30 m plots per site, where DBH and total height were measured for all individuals.

METHOD

Study area



Data Collection and Sampling Design

To model the relationship between diameter at breast height (DBH) and total tree height, data were collected from 240 systematically established plots across the study area. Within each of the twelve identified populations, 20 plots (30 × 30 m each) were randomly positioned to ensure equal representation of *Alnus glutinosa* stands on both riverbanks. For every plot, tree-level variables—including DBH, total height, and density—were recorded following established forest inventory protocols (Li et al. 2015; Sharma et al. 2019; Ogana and Ercanli 2022; Tanovski et al. 2023). Silvicultural treatments were consistent across all sampled stands. From a total of 1,066 measured trees, plot-level metrics were calculated, including mean DBH, mean height, quadratic mean diameter (QMD), mean Loray height (LH), and stem density per hectare (Tanovski et al. 2023).

Model Development and Selection

To develop new H-DBH models for *A. glutinosa* within its Moroccan range, 37 theoretical functions were selected from widely cited forestry literature based on criteria of predictive accuracy, simplicity, and biological logic (Li et al. 2015; Ciceu et al. 2020; Han et al. 2021; Raptis et al., 2024). Each model was fitted to the dataset of 1,066 trees using DBH as the predictor and total height as the response variable. Model parameters (e.g., *a*, *b*, *c*) and their standard errors were estimated for both linear and nonlinear formulations, with particular attention to functions previously applied to *A. glutinosa* or similar riparian species.

Model Evaluation

Model performance was evaluated using multiple statistical criteria:

1. Root mean square error (RMSE) and mean absolute error (MAE) as measures of prediction precision;
2. Coefficient of determination (R^2) and correlation coefficient (R) to assess explained variance and variable association;
3. Bias to quantify systematic deviation between observed and predicted values;
4. Akaike's Information Criterion (AIC) for model selection, where lower values indicate a better balance of fit and parsimony;
5. Model prediction accuracy (MPA), a composite metric integrating bias and error variability.

All statistics were calculated following established methodologies (Tanovski et al., 2023; Yin et al. 2023; West et al. 2025).

Statistical Analysis

All analyses were conducted in R version 3.4.0 (R Core Team 2017). Stratified sampling procedures were implemented using the sampling package. Linear and nonlinear mixed-effects models were fitted with the nlme package (Pinheiro et al. 2018). Data manipulation and visualization were performed using the plyr and ggplot2 packages, respectively (Wickham 2016; Chai et al. 2018).

RESULTS & DISCUSSION

Table 1: Descriptive statistics for stand elements. ; BDH: diameter at breast height; BA:basal area; QMD:mean quadratic diameter; LH – mean Loray height; nb. – number; ha:hectar

	DBH (cm)	Height (cm)	BA ($m^2 \cdot ha^{-1}$)	QDM (cm)	LH (m)	nb of trees/ha)
Mean	36.767	9.546	12.047	38.171	11.518	88.833
Minimum	6.685	2.000	0.772	33.058	7.466	54.000
Maximum	68.437	18.000	15.618	45.973	13.815	157.000
Coefficient of variation	39.3	48.3	32.2	8.801	11.182	27.705
Std. Error of Mean	0.443	0.141	0.118	4.095	1.727	24.611
Std. Deviation	14.467	4.614	3.882	3.360	1.289	32.649

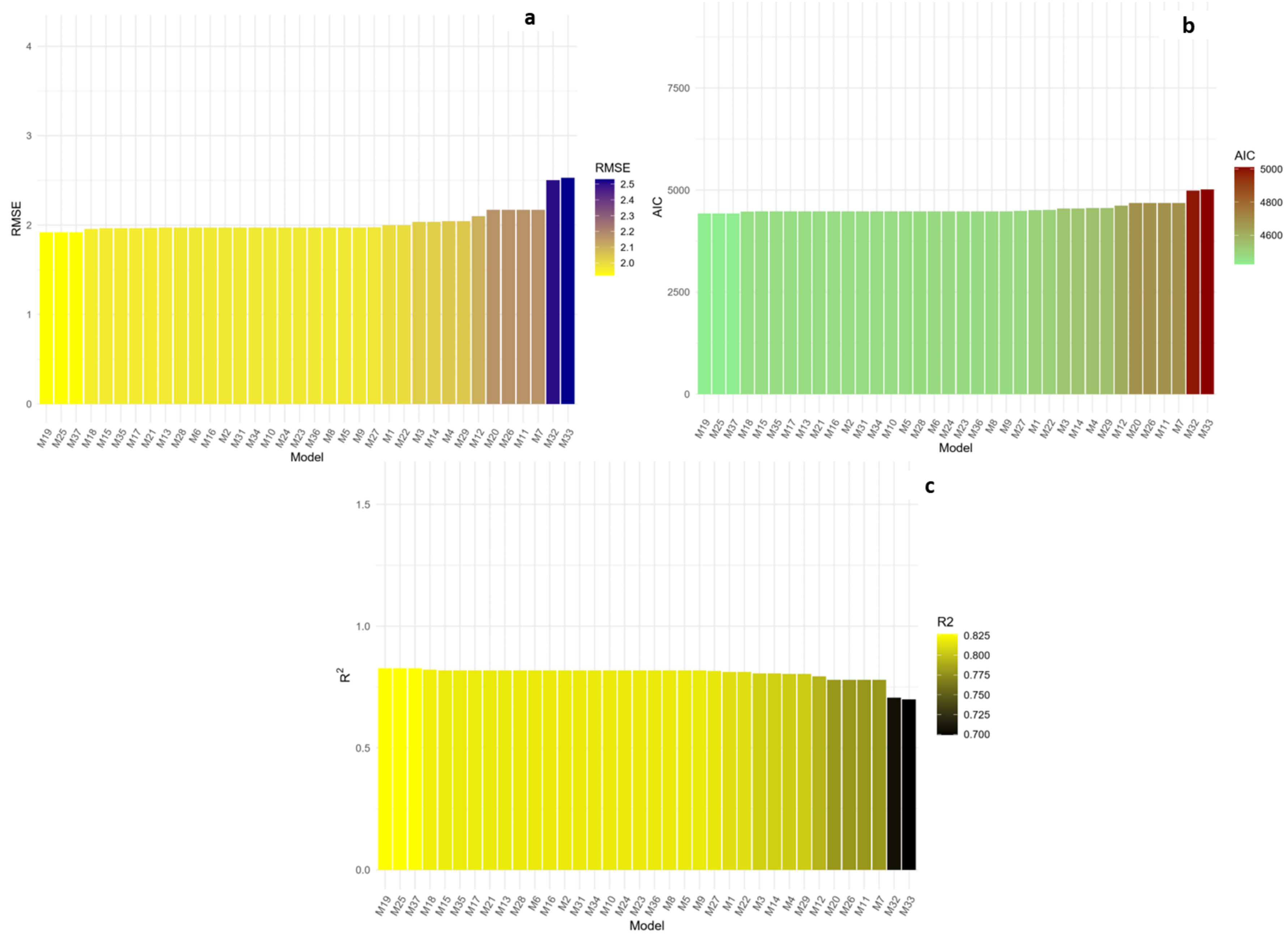


Figure 1: Model performance for: (a): RSME, (b): AIC, and (c): R^2

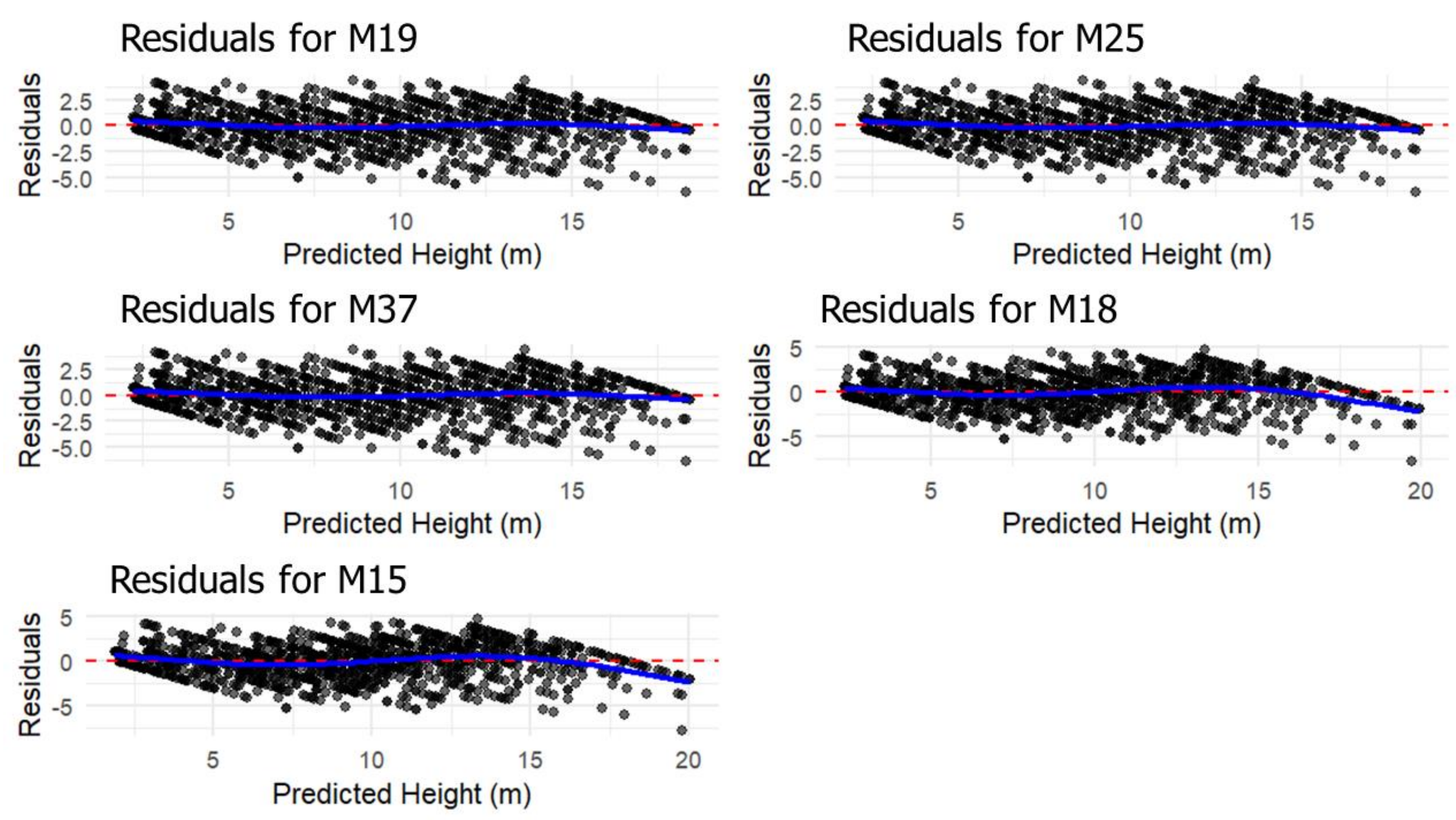


Figure 5: Scatter plot of Residual for the Best five models for tree height prediction. X-axis → Predicted tree height (m), Y-axis (Residuals = Observed Height − Predicted Height); Black points (Individual residuals for each observation); Red dashed line ((y = 0; Perfect fit (no error)); Blue smooth line (Trend of residuals (loess smoothing)).

CONCLUSION

Among the 37 candidate models evaluated, five non-linear formulations, those by Strand (1859), Fast & Ducey (2011), Peschel (1838), Pearl and Reed (1920), and El Mamoun et al. (2012) demonstrated the best goodness of fit and were selected as the most accurate predictors of tree height for this species

FUTURE WORK / REFERENCES

The selected models provide a practical and reliable tool for estimating individual tree height in stands where direct height measurements are unavailable, thereby supporting improved forest inventory, biomass estimation, and management planning for this ecologically important riparian species.

Ciceu A, Garcia-Duro J, Seceleanu I, Badea O. 2020. A generalized nonlinear mixed-effects height–diameter model for Norway spruce in mixed-uneven aged stands. Forest Ecology and Management, 477. https://doi.org/10.1016/j.foreco.2020.118507