

Allometric Equations of Major Tree Species of Nepal

(Volume I)



Government of Nepal
Ministry of Forests and Environment
Forest Research and Training Centre
Kathmandu, Nepal



December, 2025

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Foreword

Nepal's forest policy relies on maintaining at least 40 percent forest cover for biodiversity conservation and a healthy ecosystem. These forest resources have been assessed periodically through the forest resource assessment (FRA) program. The FRA in Nepal has evolved significantly, moving from broad-based estimations to a demand for precise, scientifically rigorous data. Periodic assessment of the forest resources in Nepal has generated forest statistics in terms of forest area, stem volume, basal area, stem density, biomass, carbon and other variables. These statistics show the state of forests in Nepal and help inform evidence-based decision-making and also for international reporting. The estimation of volume and biomass of the forests uses allometric equations. However, the allometric equations used in Nepal for generating national-level forest statistics contain higher uncertainties. Thus, Nepal needs its own country-specific allometric equation to generate robust estimation of tree volume and biomass.



This comprehensive report on the development of nationally-specific allometric equations for seven major tree species marks a significant milestone in Nepal's journey towards enhanced forest governance and climate action. The application of these allometric equations is directly linked to Nepal's active participation in global climate change mitigation efforts, particularly through carbon trading mechanisms such as REDD+ (Reducing Emissions from Deforestation and Forest Degradation) program. Moreover, it also helps address obligatory international reporting such as Nationally Determined Contribution (NDC), National Communication and Biennial Transparency Report to UNFCCC.

This report represents a critical step for Nepal in transitioning from the IPCC's Tier 1 methods, which use global default values, to Tier 2 or higher approaches that utilize country-specific data. This transition is expected to enhance the credibility, transparency, and value of our national carbon accounting, ensuring that Nepal receives fair compensation for its conservation efforts. Moreover, the comprehensive report on allometric equations for Nepal is a testament to years of dedicated scientific endeavor. It represents a significant leap forward in our technical capacity and strengthens our position.

The report is a unique and historic achievement in its own right. I would like to extend my deepest thanks to Dr. Rajendra KC, Director General of the Forest Research and Training Centre and his entire team for their unwavering effort while producing this invaluable report. I hope that this report will act as a foundation for producing reliable forest statistics and increase transparency at the forest and climate change mitigation interface. Most importantly, it will empower us to make informed policy and management decisions on the ground.

Date: 07/12/2025

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Rajendra Prasad Mishra, PhD
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First and foremost, I would like to express my sincere gratitude to the World Bank-funded *Forests for Prosperity Project (P170798)* for its financial support, which made the development of allometric equations for seven major tree species (Phase I) possible. I also thank sincerely to the REDD Implementation Centre for its excellent coordination and support.



I am very much grateful to the Department of Forests and Soil Conservation and the Department of National Parks and Wildlife Conservation for their crucial support in advancing this initiative. Furthermore, I acknowledge the tremendous efforts of all service providers, consultants and their dedicated teams in conducting the tree harvesting and data collection. My sincere appreciation goes to the provincial forestry ministries, Division Forest Offices, Protected Area Offices, Community Forestry User Groups, and Buffer Zone Committees for their excellent coordination and vital support during the fieldwork.

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While acknowledging all your unwavering support and dedication in carrying out extremely difficult and challenging tasks, FRTC promises to publish a series of technical papers on tree taperness—including form factors, biomass expansion factors, and the geographical influences on wood density, taperness and biomass —by 2026. Likewise, the allometric equations for an additional nine tree species (Volume II) are planned for publication by 2027. My sincere appreciation and deepest gratitude go to all FRTC colleagues, its esteemed alumni, field staff, and experts who always encouraged us to work hard to achieve this milestone.

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.....
Rajendra KC, PhD
Director General



Table of Contents

Executive Summary.....	3
1. Introduction	5
1.1 Background	5
1.2 Objectives.....	6
1.3 Rationale for Developing Country Specific Allometric Equations	6
2. Methodology	9
2.1 Study Site	9
2.2 Sampling Design and Tree Selection	9
2.2.1 Sampling Design	9
2.2.2 Determination of Sample Size.....	10
2.2.3 Stratification of Sample Trees by Diameter Classes	10
2.2.4 Allocation of Sample Trees to the Diameter Class	12
2.2.5 Identify Possible Sample Trees	12
2.2.6 Selection of Final Sample Trees.....	13
2.3 Field Measurements.....	13
2.3.1 Measurements Before Felling Sample Trees	14
2.3.2 Measurements After Felling Sample Trees	14
2.4 Laboratory Process	16
2.5 Data Checking and Cleaning.....	17
2.6 Data Processing	18
2.6.1 Volume Calculation.....	18
2.6.2 Density Estimation.....	19
2.6.3 Biomass Estimation.....	19
2.7 Predictive Model Development.....	20
2.8 Model Selection	20
2.9 Model Validation	21
3. Results	23
3.1 Allometric Equations for Volume	23
3.1.1 Total Stem Volume Over-bark	23
3.1.2 Under-bark Stem Volume up to Top 20 cm Over-bark Diameter.....	25
3.1.3 Under-bark Stem Volume up to Top 10 cm over-bark diameter	28
3.2 Allometric Equations for Biomass.....	30
3.2.1 Total Biomass	30
3.2.2 Stem Biomass	33
3.3 Testing Biomass Models Using Species Average Density.....	36
3.4 Model Validation	37
3.5 Average Wood Density.....	39
4. Discussion	42
5. Conclusions and Recommendations	46
References	47
Annexes	51

List of Table

Table 1:	Species-wise number of sample trees	10
Table 2:	Species-wise allocation of sample trees	12
Table 3:	Discs measured across different diameter classes (OB)	16
Table 4:	Examined model forms for volume	20
Table 5:	Examined model forms for biomass	20
Table 6:	Summary statistics of best fitted model for total stem volume (over bark)	23
Table 7:	Summary statistics of best fitted model for stem volume (under bark) up-to top 20 cm diameter	26
Table 8:	Summary statistics of best fitted model for stem volume (under bark) up to 10 cm top diameter	28
Table 9 :	Summary statistics of best fitted model for total biomass of all seven species	31
Table 10:	Summary statistics of best fitted stem biomass models of all seven species	33
Table 11:	Recommended density for total and stem biomass models	36
Table 12:	The comparison of suggested models through the RMSE of leave one out cross validation	38
Table 13:	Average density of stem	40
Table 14:	Average density of stem and branches	40

List of Figure

Figure 1:	The map of study area showing the distribution of permanent sample plots	9
Figure 2:	Flowchart of the tree sampling approach.....	11
Figure 3:	Distribution (location) of sampled trees of seven major tree species	13
Figure 4:	Positions of diameter and disc measurements along the tree trunk	14
Figure 5:	The visualization of province and specieswise height diameter ratio	17
Figure 6:	Distribution of sample trees according to the diameter classes by species.....	18
Figure 7:	Graphical presentation of residuals of selected models for total stem volume	25
Figure 8 :	Graphical presentation of residuals of selected models for stem volume up to top 20 cm diamete	28
Figure 9:	Graphical presentation of residuals of selected models for stem volume up to 10cm top diameter	30
Figure 10:	Graphical presentation of residuals of selected total biomass models	33
Figure 11:	Graphical presentation of residuals of selected stem biomass models	35
Figure 12:	Models validation through independent datasets.	37

Abbreviations and Acronyms

AIC	Akaike Information Criterion
An	<i>Alnus nepalensis</i>
Cs	<i>Castanopsis</i> spp.
DBH	Diameter at Breast Height, (1.3 m from ground level)
DFRS	Department of Forest Research and Survey
FAO	Food and Agriculture Organization
FRA	Forest Resource Assessment
FRTC	Forest Research and Training Centre
GHG	Greenhouse Gas
IPCC	Intergovernmental Panel on Climate Change
Lp	<i>Lagerstroemia parviflora</i>
LOOCV	Leave One Out Cross Validation
MBE	Mean Bias Error
MRV	Measurement, Reporting, and Verification
OB	Over Bark
Pr	<i>Pinus roxburghii</i>
REDD+	Reducing Emissions from Deforestation and Forest Degradation
RMSE	Root Mean Square Error
Sr	<i>Shorea robusta</i>
Sw	<i>Schima wallichii</i>
Ta	<i>Terminalia alata</i>
UB	Under Bark
UNFCCC	United Nations Framework Convention on Climate Change

Terminology

Air Dried Density: The relatively stable weight of wood at room temperature per unit fresh volume of same wood. The moisture content of the wood would be different from sample to sample or within the sample depending on time of measurement.

Basic Wood Density: The oven dried weight of wood per unit volume of fresh condition (oven dried wood density) and comparable with other pieces or species of wood anywhere in the world. According to IPCC this word does not include the bark of wood.

Biomass Expansion Factor: A multiplication factor that converts the oven dry weight of stem biomass into total biomass of branch and stem.

Diameter Class: The group of trees falls within specified diameter at breast height (DBH) interval.

Disc: This is the sub-sample of stem and large branches or small branches. Disc refers to both either with bark or without bark.

Foliage: The live leaves/needles and twigs of a tree. In the case of biomass, this is strictly the mass of the photosynthetic material, exclusive of fine branches. All the foliage were further grouped into leaves including twigs flowers, fruits/seeds or cones.

FRTC: is a departmental-level entity mandated to conduct forestry research, generate forest statistics, and implement outreach programs under the Ministry of Forests and Environment. It was formerly known as the Department of Forest Research and Survey (DFRS).

Large Branch: A woody offshoot from the stem or primary or secondary branch exceeding a minimum diameter ≥ 10 cm over bark.

Permanent Plots: The permanent georeferenced forest inventory plots established and measured

for the national forest inventory with the aim to monitor forests.

Sample tree: The tree selected for felling, measurement and utilization for model fitting.

Small Branch: A woody offshoot from the stem or a large branch that is less than a 10 cm over bark diameter. Moreover, small branches are further subdivided into: a) large branch section (LB, 7.5 to <10 cm OB diameter); medium branch section (MB, 4.5 to <7.5 cm overbark diameter) and tiny branch section (SB, < 4.5 cm overbark diameter).

Stem: The main woody axis of a tree, extending from the ground level or root collar up to a tip of the tree or minimum diameter limit of 10 cm or 20 cm overbark diameter if specified as top 10 or 20 cm stem. In the case of volume and biomass estimation stump is excluded.

Stem Volume: The cubic content (mass) of the tree stem, measured from the stump height (30 cm above ground) up to a specified top diameter limit or the tip of the tree.

Stump: The bottom section 30 cm height above ground level of tree stem left on ground when trees are felled.

Sub-sample: The parts of sample tree taken from specified position in the field for further measurement and determination of oven dried weight and/or density. This term implies stem, branches, bark, foliage, fruit, cone or flower separately.

Wood Density: The weight of wood of different moisture content conditions per unit of volume of different moisture content. The moisture content of wood is generally guided by objective of utilization.



कार्यकारी सारांश

नेपालको ४६ प्रतिशत भू-भाग ढाकेको वनक्षेत्र समग्र ग्रामीण जीविकोपार्जन र देशको आर्थिक विकास, जैविक विविधताको संरक्षण र जलवायु परिवर्तनको असरबाट हुने क्षति कम गर्न जलवायु अनुकूलन तथा न्यूनीकरण कार्यको लागि अत्यन्त महत्त्वपूर्ण रहेको छ ।

वनको दिगो व्यवस्थापन तथा कार्वन अभिलेख तयार गर्न वनमा रहेका काठको कूल आयतन (Wood volume), बायोमास (Biomass) तथा काठको घनत्व (Density) लगायत अन्य विभिन्न सूचकहरूको भरपर्दो र विश्वशनीय तथ्याङ्कहरूको आवश्यकता पर्दछ । वनमा रुखहरूको आयतन तथा बायोमास प्रत्यक्ष मापन गर्न अत्यन्तै गाह्रो, धेरै समय लाग्ने, खर्चिलो एवम् अव्यवहारिक समेत हुने भएको हुँदा वनमा सजिलै र प्रत्यक्ष मापन गर्न सकिने रुखको छातीको उचाईको ब्यास (DBH) र उचाइ (Height) को आधारमा वनमा अवस्थित रुखहरूको आयतन तथा बायोमास पत्ता लगाउन एलोमेट्रिक समीकरण (Allometric equation) निर्माण गरी प्रयोग गर्ने गरिन्छ । यसरी शुद्धताका साथ विश्वशनीय एवं बैज्ञानिक तरिकाले आफ्नो देशको भौगोलिक र वातावरणीय अवस्था अनुसारको प्रजातिगत (Species-specific) निर्माण गरिएका एलोमेट्रिक समीकरणहरू सफल नीति निर्माण, कार्वन व्यापारका लागि आवश्यक सुदृढ अनुगमन, प्रतिवेदन तथा प्रमाणीकरण (Monitoring, Reporting and Verification) प्रणाली विकास र सञ्चालन गर्न एवम् अन्तर्राष्ट्रिय रूपमा उपलब्ध प्रतिष्पर्धी कार्वन बजारमा सहभागी भई अधिकतम फाइदा प्राप्त गर्नका लागि वैज्ञानिक आधार प्रदान गर्दछ ।

जलवायु परिवर्तन सम्बन्धी अन्तरसरकारी प्यानल (IPCC) को निर्देशिका अनुसार कार्वन उत्सर्जन मापनका लागि स्तर-१ (Tier 1) भन्दा स्तर-२ (Tier 2) र स्तर-३ (Tier 3) विधिहरूलाई अधिक सटिक (Precise), सही र विश्वनीय मानिन्छ । माथिल्लो स्तरमा स्तर वृद्धि हुन देश-विशेष र प्रजाति-विशेषका आफ्नै एलोमेट्रिक समीकरणहरू विकास गर्नु जरुरी हुन्छ । तर, हालसम्म बृहत्तर अध्ययन र अनुसन्धानको अभावमा हाम्रो देश पारम्परिक रूपमा सीमित वा बाह्य स्रोतबाट साभार गरिएका बायोमास र प्रजाति घनत्व मानहरू प्रयोग गर्ने सामान्यीकृत मोडेलहरूमा निर्भर रहेको छ ।

विश्व बैंकको "समृद्धिका लागि वन (P170798)" परियोजनाको अनुदान सहयोगमा देशको कुल काण्ड आयतनको करीब ४०% भाग ओगट्ने सात प्रमुख रुख प्रजातिहरू (साल, असना, बोटधंगैरो, उत्तिस, खोटेसल्लो, चिलाउने र कटुश) का लागि एलोमेट्रिक समीकरण निर्माण गर्ने कार्यको सम्पन्न भएको छ । यसले हरित गृह ग्याँस उत्सर्जनको प्रतिवेदन तयारीमा आउन सक्ने अनिश्चितता कम गर्न, वन मापन कार्यलाई सुदृढिकरण गर्न, सामाजिक-आर्थिक लाभलाई बृद्धि गर्न र हामी जस्तै अन्य देशहरूका लागि बैज्ञानिक रूपमा एलोमेट्रिक समीकरण निर्माण गर्न सहयोग पुग्ने देखिन्छ ।

यस अध्ययनका लागि रुख छनौट गर्दा नेपालको वनको पर्याप्त र निष्पक्षतापूर्वक प्रतिनिधित्व सुनिश्चित गर्न पहिलो चरणमा तत्कालीन वन अनुसन्धान तथा सर्वेक्षण विभाग (DFRS) ले तेस्रो राष्ट्रिय वन स्रोत आकलन (सन् २०१०-२०१४) को क्रममा स्थापना गरेका स्थायी नमूना प्लटहरूलाई आधार लिइएको थियो । मूलतः वन स्रोत सर्वेक्षण प्रतिवेदनमा उल्लेखित कूल काण्ड आयतनका साथै अन्य बहुमापदण्डहरूको आधारमा छनौट गरिएका प्रत्येक प्रजातिहरूको कटान गरिने रुखहरूको संख्या निश्चित ब्यास वर्ग (Diameter class) भित्र उपलब्धताको आधारमा समानुपातिक पर्ने गरी निर्धारण गरिएको थियो ।

अध्ययनको निष्पक्षता बृद्धि गर्न र सबै ब्यास वर्गको प्रयाप्त संख्यामा रुख छनौट गर्ने उद्देश्यका लागि वन अनुसन्धान तथा प्रशिक्षण केन्द्रले सन् २०२० मा तयार गरेको रुख छनौट गर्ने गाइडलाइनको आधारमा वन स्रोत सर्वेक्षण (FRA)ले विगतमा देशका विभिन्न स्थानहरूमा स्थापना गरेका स्थायी नमूना प्लटहरूको वरिपरि नमूनाका लागि एलोमेट्रिक समीकरण बनाउन चाहिने भन्दा ४ गुणा बढी रुखहरू पहिलो चरणमा पहिचान गरी चिनो लगाइएको थियो । यी रुखहरूमध्ये न्याण्डम (Random) विधिबाट मापनका लागि नमूना रुखहरूको आवश्यक संख्यामा छनौट गरिएको थियो । वन अनुसन्धान तथा प्रशिक्षण केन्द्रले तयार गरेको स्याम्पलिङ्ग र मापन प्रोटोकलहरू प्रयोग गरी फिल्डमा रुख तथा अन्य नमूनाहरूको मापन तथा संकलन व्यवस्थित रूपमा गरिएको थियो ।

रूख काट्नु भन्दा अगाडी साइट (Site), स्ट्यान्ड (Stand), र रूखको विवरणहरु संकलन गरी अभिलेख गरिएको थियो। रूख काटेपश्चात, रूखको फेदबाट टुप्पो सम्मको पूर्वतय गरिएको दूरी अन्तराल (Predefined interval) मा “बोक्रा सहित” र “बोक्रारहित” काण्ड तथा हाँगाविगाहरुको ब्यास मापन गरिएको थियो । समय, साधन र स्रोतमा मितब्ययताका लागि ब्यास मापन गरिएका सबै स्थानबाट काठको डिस्क संकलन नगरी एक स्थान छोडी अर्को स्थान अर्थात प्रत्येक वैकल्पिक मापन बिन्दु (Alternate measurement point) बाट काण्ड तथा हाँगाका नमूना डिस्कहरु संकलन गरिएको थियो । ती संकलन गरिएका काठका डिस्कहरुको फिल्डमा नै हरिततौल (Fresh weight) १ ग्राम सम्मको शुद्धताका साथ डिजिटल तौल मेशिन र आयतन १ घन सेन्टिमिटरको शुद्धताका साथ आर्केमिडिजको सिद्धान्तमा आधारित पानी विस्थापन विधिबाट मापन गरिएको थियो ।

यसका साथै साना हाँगाहरु र पातहरु फिल्डमा नै प्रत्यक्ष रूपमा तौलिएको र केही नमुनाहरु समेत लिइएको थियो । वन अनुसन्धान तथा प्रशिक्षण केन्द्रमा रहेको बायोमेट्रिक प्रयोगशालामा विश्लेषण गर्नका लागि नमूना डिस्कहरु संकलन गरी काठमाडौ ल्याइएको थियो । संकलन गरी काठमाडौ ल्याइएका सबै नमूना डिस्कहरु हावाले सुकाएको (Air dry) तौल मापनका लागि १ वर्ष भन्दा बढी समयसम्म हावामा सुकाइएको थियो । यसको पटक पटक तौल मापन गरी एकै किसिमको तौल नआउँदासम्म तौल मापन गर्ने र एकै किसिमको तौल आएपछि सोहीलाई नै हावाले सुकाएको तौलको रूपमा गणना गरिएको थियो । यसैगरी विद्युतीय ओभनमा डिस्कहरु सुकाए पछि निरन्तर तौल मापन गर्ने र सुकेर घटिरहेको तौल स्थिर भएपछि सोही तौललाई नै ओभनमा सुकाएको (Oven dry) तौलको रूपमा गणना गरिएको थियो । संकलन गरिएका तथ्याङ्कहरुलाई तार्किक एकरूपता (Logical consistency) विधिबाट जाँच गरी शुद्धता अनुमोदित गरिएको थियो । यसरी परीक्षण पश्चात सात प्रजातिका जम्मा ४७६ वटा नमूना रूखहरुबाट एलोमेट्रिक समीकरण (Allometric equation) हरू तयार गरिएको हो ।

एलोमेट्रिक समीकरण निर्माण तथा कार्बन मोडेलिङ अनुसन्धानका लागि वृहत्तरूपमा प्रचलित तथा स्थापित मान्यताका आधारमा सातवटै प्रजातिहरुको लागि बोक्रा सहित (Over bark) कुल काण्ड आयतन (Stem volume) तथा बोक्रारहित (Under bark) को २० से.मी. र १० से.मी. टुप्पो व्याससम्म मोटाइको काण्ड आयतन मापनका लागि ३ वटा रेखीय (Linear) र ३ वटा गैर-रेखीय (Non-linear) मोडेलहरु परीक्षण गरिएको थियो । यस बाहेक, प्रत्येक प्रजातिको कुल बायोमास (Total biomass) र स्टेम बायोमास (Stem biomass) शुद्धताका साथ अनुमान गर्नका लागि थप ५ वटा गैर-रेखीय उम्मेदवार मोडेल (Candidate model) हरू समेत परीक्षण गरिएका थिए । यी ५ उम्मेदवार मोडेलहरुको प्रभावकारिता र शुद्धता मूल्याङ्कन अकाइक इन्फर्मेसन क्राइटेरियन (AIC), रूट मीन स्क्वायर्ड एर (RMSE), मीन बायस एर (MBE) र अवशेषहरु (Residuals) को ग्राफिकल विश्लेषण र तुलना गरी प्रजातिगत रूपमा श्रेष्ठतम् मोडेल एलोमेट्रिक समीकरणको रूपमा सिफारिश गरिएको छ ।

यो प्रतिवेदनमा नेपालका सात प्रमुख रूख प्रजातिहरुको लागि काण्डको बायोमास, कुल बायोमास (काण्ड, हाँगा, र पात) र आयतन (काण्ड) पत्ता लगाउनका लागि प्रजातिगत एलोमेट्रिक समीकरणहरु तयार गरी सिफारिश गरिएको छ । यसका साथै काण्डको तुलनामा हाँगाहरुको बायोमास र आयतनको अनुपात समेत सरल रूपमा दिइएको छ । साथै प्रजातिगत रूपमा काठको हावामा सुकेको र ओभनमा सुकेको काठको घनत्व तयार गरिएको छ । यी नतिजाहरुले नेपालको भावी राष्ट्रिय वन स्रोत गणनालाई थप सुदृढ र विश्वशनीय बनाउन, सशक्त कार्बन मापन प्रणाली (Carbon accounting) तयार गर्न एवम् वन व्यवस्थापनको लागि वैज्ञानिक आधार प्रदान गर्दछ । यसले प्रमाणमा आधारित वन नीति निर्माण, वन व्यवस्थापनका विधिहरु पहिचान र लागु गर्नका साथै नेपालले अधिकतम लाभ प्राप्त गर्ने गरी कार्बन व्यापार प्रणालीहरुमा प्रभावकारी भूमिका खेल्नमा महत्वपूर्ण सहयोग पुऱ्याउने अपेक्षा गरिएको छ ।

Executive Summary

Nepal's forests, covering 46% of the country, are vital for rural livelihoods and economic development of the country, biodiversity conservation and climate change adaptation and mitigation. Precise data on volumes, biomass, wood density, and other key tree variables are essential for sustainable forest management and carbon accounting. Since direct measurement of tree volume and biomass is difficult, time consuming and costly, allometric equations-linking easily measurable variables like tree diameter and height to biomass and carbon-provide a scientific basis for sound policy formulation, robust monitoring, reporting and verification systems development, and participation in carbon markets. The Intergovernmental Panel on Climate Change (IPCC) guidelines recommends Tier 2 and Tier 3 methods as higher-tier approaches, which are generally regarded as more accurate for estimating emissions. In the forestry sector, developing country-specific allometric models is essential for advancing to these higher tiers. However, Nepal has traditionally relied on generalized models that use biomass and species density values derived from limited or externally sourced data. The World Bank funded ongoing "Forests for Prosperity (P170798)" Project has supported to fulfill this gap by developing national-level equations for seven major tree species, representing almost 40% of the country's total stem volume, which will reduce uncertainties in the Greenhouse Gas (GHG) reporting, strengthen forest inventories, and maximize socio-economic benefits, while also serving as a model for other countries.

The permanent sample plots, established during the third national Forest Resource Assessment (FRA; 2010-2014) by then Department of Forest Research and Survey (DFRS), were used as the basis for the first-phase sampling to ensure the adequate representation of Nepal's forests. The total number of sample trees, both within and across diameter classes for each species, was determined by multi criteria primarily based on the percentage share of total number of trees and stem volume of Nepal. To ensure adequate representation, four-fold than the required number of potential candidate trees were initially selected and marked around the FRA sample plots, following established tree

selection guidelines. From this pool, the final sample trees were randomly chosen.

Using the approved sampling and measurement protocols, field measurements and sample collections were carried out systematically. Site, stand, and tree-level information were recorded prior to tree felling. After felling, over-bark and under-bark diameters were measured from the base to the tip of the stem, including branches, at predefined intervals.

Sample discs were collected at every alternate measurement point, and their fresh weight and volume were determined in the field using a digital balance and the water displacement method. All the small branches and foliage were weighed directly in the field and samples were collected for further laboratory analysis. All subsamples (discs) were air-dried and oven-dried to a constant weight. Data were checked and verified using logical consistency. Then altogether 476 sample trees of seven species were used for model fitting.

Based on their established performance and widespread adoption within forestry allometry and carbon modeling research, three linear and three nonlinear candidate models were tested for each of the seven species for over-bark total stem volume and under-bark volume up to 20 cm and 10 cm top diameter. Additionally, five nonlinear candidate models were tested for total biomass and stem biomass of each species. Candidate models were evaluated using Akaike Information Criterion (AIC), Root Mean Squared Error (RMSE), Mean Bias Error (MBE) and graphical analyses of residuals.

This report presents a comprehensive set of species-specific allometric equations for the seven major tree species of Nepal, including total biomass (stem, branch, and foliage) and stem volume models upto specified diameters. It also establishes robust wood density benchmarks and a conversion ratio from stem volume to branches and stem biomass to total biomass. Together, these outputs provide a scientifically grounded foundation for national forest inventory, carbon accounting and support Nepal's readiness for evidence-based forest policy, management interventions and carbon trading mechanisms.



1. Introduction

1.1 Background

Nepal's forests, which share 46.08% of the country's area (FRTC, 2024), are critical to its ecological stability and enhancing rural livelihoods and promoting the nation's economy. They are essential for biodiversity, soil and water conservation, climate regulation, and providing subsistence resources like fuelwood, fodder, and timber for millions. To maximize their socio-economic benefits through sustainable management, robust and reliable data on forest conditions is a prerequisite.

Since directly measuring key indicators like volume and biomass is complex and challenging, allometric equations serve as a vital scientific tool. These equations use easily measurable variables (e.g., tree diameter, height) to reliably predict volume and biomass, providing reliable data for effective forest policy and management.

Forests act as vital carbon sinks, absorbing atmospheric carbon dioxide through photosynthesis and storing vast amounts of carbon in their biomass. Conversely, they become significant carbon sources when this stored carbon is released through deforestation and degradation (Pearson *et al.*, 2017). Robust biomass allometric equations are therefore essential for quantifying both carbon sequestration and emissions.

While land-use change is estimated to contribute approximately 12% of global anthropogenic greenhouse gas emissions (IPCC, 2006), this figure carries substantial uncertainty due to inconsistent and insufficient biomass estimation models (Brown *et al.*, 1995). Developing a sufficient number of robust and reliable allometric models is critical to reduce this uncertainty.

Tree-level allometric equations are the standard method for estimating individual tree volume and biomass and are essential for scaling up to national forest inventories (Khanal *et al.*, 2024). These equations predict wood volume, biomass, or carbon stock based on variables like tree diameter and height. The development of these equations depends on factors such as forest type, users' objective, legal constraints, and available resources (Picard *et al.*, 2012). Consequently, the accuracy and quality of

predictions vary significantly between models. Notably, despite a recent increase in the number of available equations, the precision of biomass estimates has not consistently improved (Henry *et al.*, 2013).

Allometric equations for estimating forest biomass operate at three primary levels: individual tree, stand, and forest type. Individual tree-level models are the foundational basis for developing more complex equations at higher levels and are primarily used for precise estimation. The IPCC categorizes methodological approaches into a three-tiered hierarchy based on complexity and accuracy:

- ❑ Tier 1: A basic method employing generalized default equations for an ecological zone when species-specific data is unavailable.
- ❑ Tier 2: An intermediate method applied when species-specific volume equations exist. Volume is converted to biomass using wood density and a biomass expansion factor.
- ❑ Tier 3: The most complex and data-intensive method, which uses species-specific biomass equations developed from direct measurements.

While destructive harvesting to build such models is rare in the tropics (Henry *et al.*, 2011), species-specific equations are preferred due to significant interspecies morphological differences that affect biomass accumulation (Valbuena *et al.*, 2016). Precision generally increases with tier level, with Tier 3 considered the reference standard (IPCC, 2019).

For Nepal, developing robust, reliable and nation-specific allometric equations is a key strategic objective and a national forestry sector priority. As the signatory to several Multilateral Environmental Agreements and to enable its participation in the international carbon market, Nepal is obligated to report robust forest statistics to international institutions to fulfill its commitments. Higher-tier (Tier 3) equations are often required by carbon financing facilities, as they reduce uncertainty, minimize buffer allocations, and maximize potential incentives (FCPF, 2024).

Historically, Nepal's allometric models have been insufficient for modern needs. The

first national volume table was developed in the 1960s for timber production. Based on these data, the DFRS published Volume and Biomass Prediction Equations of Forest Trees of Nepal for 21 species and two species groups (miscellaneous in Terai, and Hills) (Sharma & Pukkala, 1990). The precision of the prescribed models may have been affected by the use of outdated data, collected more than 60 years ago with rudimentary techniques and less accurate instruments such as the Abney level, Pentaprism caliper, and planimeter. Subsequent biomass models, while improved, often relied on default wood density values for biomass estimates or were limited to specific sites. The gap in national-level equations was formally identified but remained unaddressed (Eerikäinen *et al.*, 2012, Subedi, 2022). Several small-scale initiatives have aimed to develop allometric volume models for selected species (e.g., DFRS, 2017, Subedi, 2017); however, these efforts are often constrained by limited sample sizes, restricted geographic coverage, and narrow species representation, among other factors. Moreover, it has not found any effort for biomass models.

The World Bank funded “Forests for Prosperity Project (P170798)” has supported Nepal in addressing these challenges. It focuses on the 16 species groups that each constitute over 1% of Nepal’s total stem volume (DFRS, 2015). The first phase targets seven major tree species that collectively account for 40.01% of the national stem volume: Sal (*Shorea robusta*; 19.28%), Khotosallo (*Pinus roxburghii*; 7.05%), Asna (*Terminalia alata*; 4.67%), Utis (*Alnus nepalensis*; 3.56%), Chilaune (*Schima wallichii*; 2.66%), Katush (*Castanopsis* spp.; 1.73%), and Botdhagero (*Lagersroemia parviflora*; 1.06%) (DFRS, 2015). The development of robust, reliable species-specific national allometric equations will significantly improve the accuracy of Nepal’s forest carbon inventories. This advancement is essential for strengthening the MRV system, fulfilling GHGs reporting obligations, and formulating evidence-based forest policy. Furthermore, the methodology developed in this study may serve as a useful guideline for other countries encountering comparable landscapes, ecological, and data challenges.

1.2 Objectives

The overall objective of this study was to enhance the accuracy and reliability of Nepal’s future national forest inventories by developing

robust country specific allometric equations. The results are expected to strengthen evidence-based forestry policy formulation and decision making, and to enhance the country’s capacity to participate effectively in emerging carbon-trading mechanisms.

The specific objectives for developing reliable, robust, and species-specific predictive allometric equations for major seven tree species in Nepal were:

- a) To prepare the volume (stem and branch) allometric equations,
- b) To construct the total biomass (stem, branch and foliage) allometric equations,
- c) To determine the species specific wood density and establish a reliable baseline between air-dry and oven-dry biomass,
- d) To recommend robust and reliable allometric equations for the national level forest inventory,
- e) To support carbon trade policy formulation and enhance national capacity.

1.3 Rationale for Developing Country-Specific Allometric Equations for Volume and Biomass

The climatic and altitudinal variations in Nepal have been playing significant roles to maintain diverse forest types. These forests have become an integral part of the rural livelihood in Nepal. Moreover, climate change initiatives like REDD+ (Reducing Emissions from Deforestation and Forest Degradation) have elevated the importance of forests due to its contribution to the national carbon sink. The contribution of forests to climate change mitigation by storing carbon varies from species to species (Baral *et al.*, 2010), depending on species characteristics and geographical distribution (Khanal *et al.*, 2024b; Ranabhat & Malla, 2023).

Tree growth, in terms of diameter and height, differs across and within species due to variations in altitude, aspect, and soil type (Coomes & Allen, 2007; Khanal *et al.*, 2025). Global/regional allometric equations cannot accurately capture this diversity, leading to large uncertainty in volume and biomass estimates. Therefore, developing country-specific allometric equations is essential to address both national and international priorities in climate change mitigation, sustainable forest management and carbon trading.

The allometric equations developed by Sharma & Pukkala, 1990 marked an important early step toward quantifying tree volume and biomass for Nepal's major forest species and have been widely used in forest inventory and carbon assessment studies. However, several limitations of their work have become apparent with the increasing demand for higher precision and transparency in emission estimation. The models were developed using a spatially undefined nondestructively measured dataset in the 1960s (Sharma & Pukkala, 1990), with tree samples that did not adequately represent the full range of diameter classes, making their application to large or mature trees less reliable. The use of undefined moisture content air-dry wood density instead of oven-dry measurements, along with less precise field instruments, may have introduced additional bias in biomass estimates. Moreover, the sampling design and measurement protocols were not clearly documented, restricting reproducibility and verification (Eerikäinen *et al.*, 2012). Consequently, while Sharma & Pukkala's study provided a valuable foundation, the development of updated species-specific models based on comprehensive sampling across diameter size classes with wider spatial variation improved estimation standards, and more diverse predictor variables is essential to enhance the accuracy of national greenhouse gas inventories and forest carbon monitoring.

A total of 16 tree species have been selected for the development of allometric equations in two phases. **Phase I** covers seven species primarily distributed from the Terai to the Mid-Hills, while **Phase II** includes the remaining nine tree species, largely distributed from the Mid-Hills to the High Mountains. These 16 tree species share more than three quarters of the total stem volume where each species shares more than 1% (DFRS, 2015). The species-specific allometric equations development in both phases, will significantly improve the accuracy and credibility of volume and biomass estimates of more than three-quarters of the country's forests (DFRS, 2015).

Nepal has been conducting periodic forest resource assessments; however, without reliable tree models, accurate forest inventory cannot be achieved. It is a crucial step towards national carbon accounting for global climate commitments such as the Paris agreement, United Nations Framework Convention on Climate Change (UNFCCC). Currently, Nepal relies on Tier 1 methods for its GHG inventories, which carry a high degree of uncertainty. Country-specific allometric equations would enable a transition to Tier 2 and above reporting, greatly enhancing the credibility of Nepal's international reporting. This, in turn, would enable the country to harness greater financial benefits from REDD+ initiatives and other carbon trading regimes.





2. Methodology

2.1 Study Site

Sal (*Shorea robusta*), Asna (*Terminalia alata*) and Botdhagero (*Lagerstroemia parviflora*) represent tropical species in Nepal, thriving in lower altitudinal regions with higher temperature mostly confined to the Terai and Siwalik regions. However, the *S. robusta* extends up to 1500 m mean sea level (msl) in the middle mountain (Jackson, 1994). The other remaining four species, Chilaune (*Schima wallichii*), Katush (*Castanopsis* spp.), Uttis (*Alnus nepalensis*) and Khotosallo (*Pinus roxburghii*) are the sub-tropical species that occur in the middle mountain and lower part of the high mountain while *A. nepalensis* is found easily up to 2700 msl. *S. wallichii* and *Castanopsis* species are confined to the eastern part of the middle mountain region of Nepal while *P. roxburghii* is more concentrated to western part of Nepal (Jackson, 1994). The map below (Figure 1) indicates these seven species found within the FRA permanent plots. This study covers the forest area throughout Terai, Siwalik,

Middle mountain and some High mountain areas of Nepal. The detail distribution and information about these spp. was given in Annex I.

2.2 Sampling Design and Tree Selection

The sampling design and tree selection involved a sequence of steps. Figure 2 presents the procedural framework for sample size and sample tree determination, outlining the main selection criteria and steps.

2.2.1 Selection of Tree Species

The Department of Forest Research and Survey (presently known as the Forest Research and Training Centre) has listed a total of 443 important tree species from FRA (2010-2014) in Nepal. Among them, there are 16 species (or group of species), each has at least one percent and they contribute a sum of 77% of total stem volume (Table 1). Among them, seven tree species from Terai, Siwalik and Middle Mountain were chosen in the first phase.

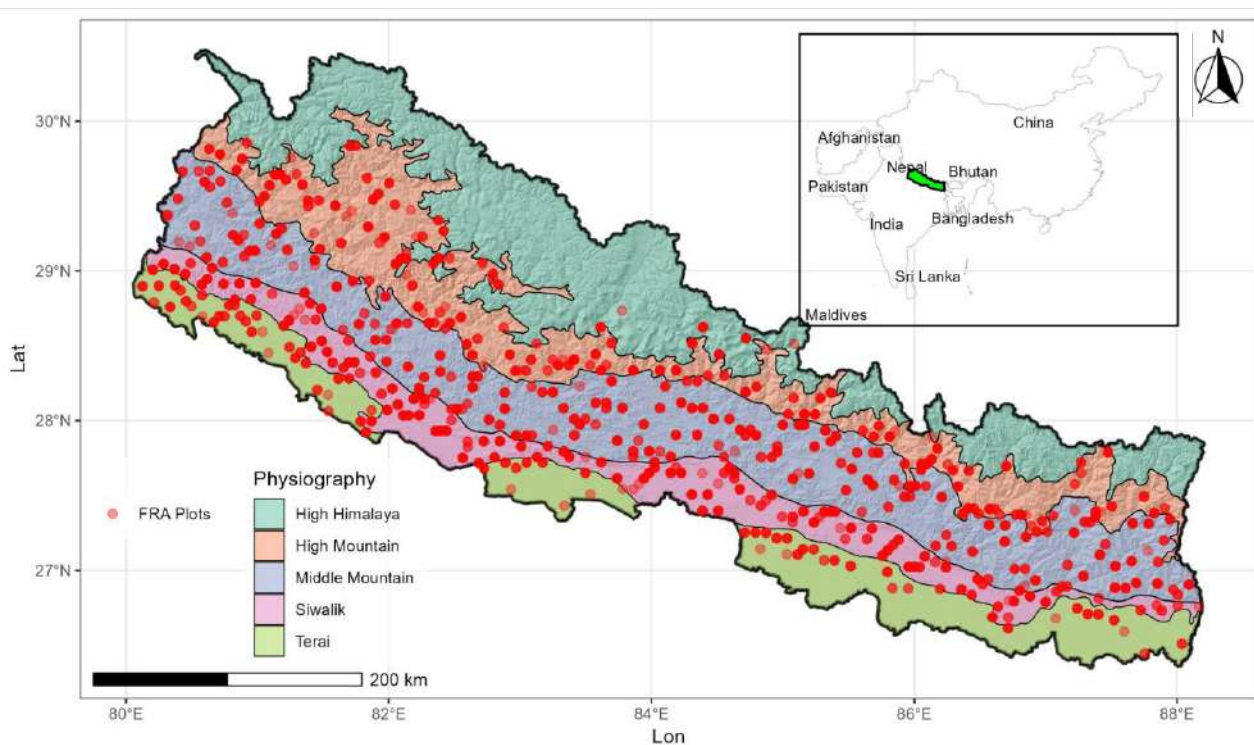


Figure 1: The map of study area showing the distribution of permanent sample plots (with seven tree species) established by FRTC (then DFRS) across all physiographic regions of Nepal.

2.2.2 Determination of Sample Size

The destructive data collection method incurs substantial costs in terms of time, finances, and ecological impact. Based on the above criteria, it was estimated to fell down approximately 1100 trees for measurement and data collection in two phases for 16 species. For species allocation, the sample size was determined based on the contribution to the total stem volume prescribed in FRA report (DFRS, 2015). Further readjustment of the number of samples per species was determined by following key criteria:

- Minimum number of sample trees (i.e. 50) was set for the equation development
- Geographical distribution of selected species (according to the DFRS, 2015)
- Relative proportion of a given species in the total stem volume. For example, Sal, Chirpine had a larger contribution to total stem volume, therefore a larger sample size was chosen.

- Whether the species was treated individually (e.g., *A. nepalensis*, *S. robusta*, *L. parviflora*, *S. wallichii*, *P. roxburghii*, *T. alata*) or as a genus-level group (e.g., *Castanopsis* spp). For instance, more samples were allocated for *Castanopsis* spp. than *S. wallichii*, though later contributed higher proportion with the objective to better represent a mix of species (3 species in this case, *C. indica*, *C. tribuloides* and *C. hystrix*).
- Availability of desired samples and the logistical feasibility within the constraints of available resources.

For seven species, a total of 496 trees were set to be sampled in the first phase to develop the allometric models. The number of sample trees was determined as shown in Table 1.

2.2.3 Stratification of Sample Trees by Diameter Classes

Stratification is an effective sampling technique that minimizes sampling error and increases

Table 1: Species-wise number of sample trees selected based on the stem volume proportion. Stem volume % have been taken from the FRA report (DFRS, 2015). Selected seven species for the first phase study are shown in bold texts and their respected proportion in the number of adjusted sample trees.

S.N.	Vernacular Name	Tree Code	Botanical name	Stem volume (% of Total)	Estimated no. of sample trees (proportional allocation)	Adjusted no. of sample trees
1	Sal	Sr	<i>Shorea robusta</i>	19.28	272	125 (11.4%)
2.	Asna	Ta	<i>Terminalia alata</i>	4.7	66	66 (6%)
3.	Utis	An	<i>Alnus nepalensis</i>	3.6	51	51 (4.7%)
4.	Katush	Cs	<i>Castanopsis</i> spp.	1.7	24	55 (5%)
5.	Botdhayero/Botdhagero	Lp	<i>Lagerstroemia parviflora</i>	1.1	16	50 (4.6%)
6.	Khote Sallo/Chirpine	Pr	<i>Pinus roxburghii</i>	7	99	99 (9.1%)
7.	Chilaune	Sw	<i>Schima wallichii</i>	2.7	38	50 (4.6%)
8.	Thingure Sallo	Ab	<i>Abies</i> spp.	4.6	65	72 (6.6%)
9.	Firfire	Ac	<i>Acer</i> spp.	1	14	55 (5.0%)
10.	Bhojpatra	Bt	<i>Betula</i> spp.	1.6	23	55 (5.0%)
11.	Angeri	Ly	<i>Lyonia</i> spp.	1.4	20	55 (5.0%)
12.	Jhulle Sallo	Pc	<i>Picea</i> spp.	1.4	20	55 (5.0%)
13	Rani Sallo	Pw	<i>Pinus wallichiana</i>	3.7	52	52 (4.8%)
14	Baanjh	Qr	<i>Quercus</i> spp.	14.8	209	120 (11.0%)
15.	Gurans	Rd	<i>Rhododendron</i> spp.	5.3	75	83 (7.6%)
16.	Tsuga	Ts	<i>Tsuga dumosa</i>	3.5	49	50 (4.6%)
Total				77.38	1093	1093 (100%)

Source: DFRS, 2015

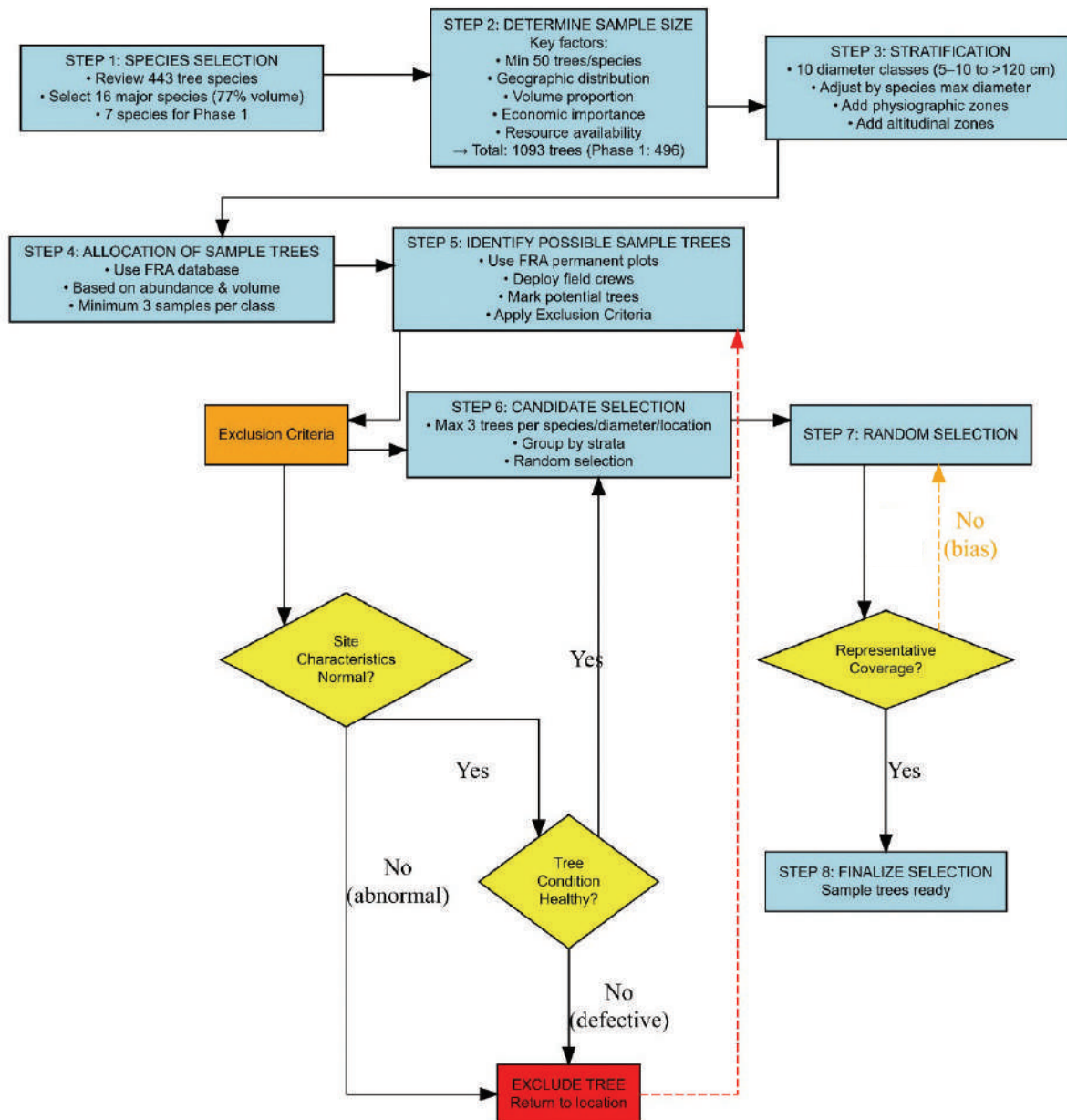


Figure 2: Flowchart of the tree sampling approach. Top row (Steps 1-3) covers species selection, sample size, and stratification; middle row (Steps 4-5) shows sample allocation and identification of sample trees; third row (Steps 6-7) represents candidate tree selection and random selection; Step 8 (bottom right) final sample tree selection. Items in the diamond shapes indicate decision points with corrective pathways shown by arrows.

estimate's precision by organizing a heterogeneous population into more homogeneous subgroups, or strata (Cochran, 1977). This method enhances accuracy while remaining cost-effective and is widely recognized in scientific literature (Van Lar & Acka, 2007; Kershaw *et al.*, 2017). A key advantage of stratification is the ability to adjust sampling intensity and precision for each individual stratum in forestry applications (McRoberts & Tomppo, 2007).

Forest ecosystems in Nepal exhibit substantial heterogeneity arising from variations in species

composition, topography, stand density, developmental stage, management history, and tree structural attributes such as size, age, and architecture. Among these factors, tree diameter at breast height (DBH) effectively integrates much of this variability, as it reflects both individual tree growth conditions and stand-level development. Because DBH is also a well-established predictor of tree volume and biomass. Thus, it was selected as the primary variable for stratification to account for this structural heterogeneity in subsequent analyses.

We classified all individual trees for sampling into ten diameter classes as 5-9.9 cm, 10-19.99 cm, 20-29.99 cm, 30-39.99 cm, 40-49.99 cm, 50-59.99 cm, 60-69.99 cm, 70-89.99 cm, 90-119.99 cm, and ≥ 120 cm (Table 2).

2.2.4 Allocation of Sample Trees to the Diameter Class

A scientifically rigorous sampling design requires a predetermined sample size. For this study, the sample size of each stratum was calculated using the proportional allocation method, which distributes samples based on the relative abundance (number of trees) and volume of trees within each diameter class across Nepal's forests (Van Lar & Acka, 2007; Kershaw *et al.*, 2017). This approach leverages prior information from the Forest Resource Assessment (FRA, 2015) database. Therefore, all proportional samples were at first estimated then adjustment was made based on possible variation on volume/biomass within diameter classes, but ensuring at least three samples within the given diameter classes (Table 2).

Consequently, diameter classes with lower number of trees in forest (i.e. trees of higher diameter classes) and lower volume/biomass yielded groups (i.e. trees of lower diameter classes) allocated smaller sample sizes, while classes with greater abundance and volume/biomass required larger numbers of samples. Based on this logic, the requisite number of sample trees for each species and diameter class were determined (Table 2).

2.2.5 Identify Possible Sample Trees

The sample selection process utilized the permanent plots established during third national Forest Resource Assessment (FRA) of the country (DFRS, 2015) as a reference for locating specific species and diameter classes. It was assumed that the potential sample trees representing required diameter classes would most likely be found around the permanent plots where those species had already been recorded during the FRA (2010-2014).

Therefore, at first, field crews were deployed near to the FRA plots to identify and mark potential sample trees, creating a comprehensive sampling frame. The crew selected and marked the first three trees of given diameter and species. A maximum of three candidate trees per species and diameter class were selected and marked from each location to avoid higher representation from one location and ensure the unbiased representation of geographical variations. To maintain data integrity, trees were excluded based on specific criteria:



- ❑ **Site Characteristics:** Trees in abnormal or non-representative locations (e.g., forest

Table 2: Species-wise allocation of sample trees (number) across various diameter classes. The acronym used for species, please refer to Table 1 above.

Species	DBH (cm)										Total Readjusted Number
	5-9.9	10-19.9	20-29.9	30-39.9	40-49.9	50-59.9	60-69.9	70-89.9	90-119.9	≥ 120	
An	3	9	11	10	7	5	3	3	-	-	51
Cs	5	9	11	10	8	6	3	3	-	-	55
Lp	6	10	10	9	6	3	3	3	-	-	50
Pr	7	12	20	17	15	12	8	5	3	-	99
Sr	7	11	14	20	21	20	15	8	6	3	125
Sw	4	10	10	10	8	5	3	-	-	-	50
Ta	5	8	9	12	10	7	4	6	3	3	66
Total	37	69	85	88	75	58	39	28	12	6	496

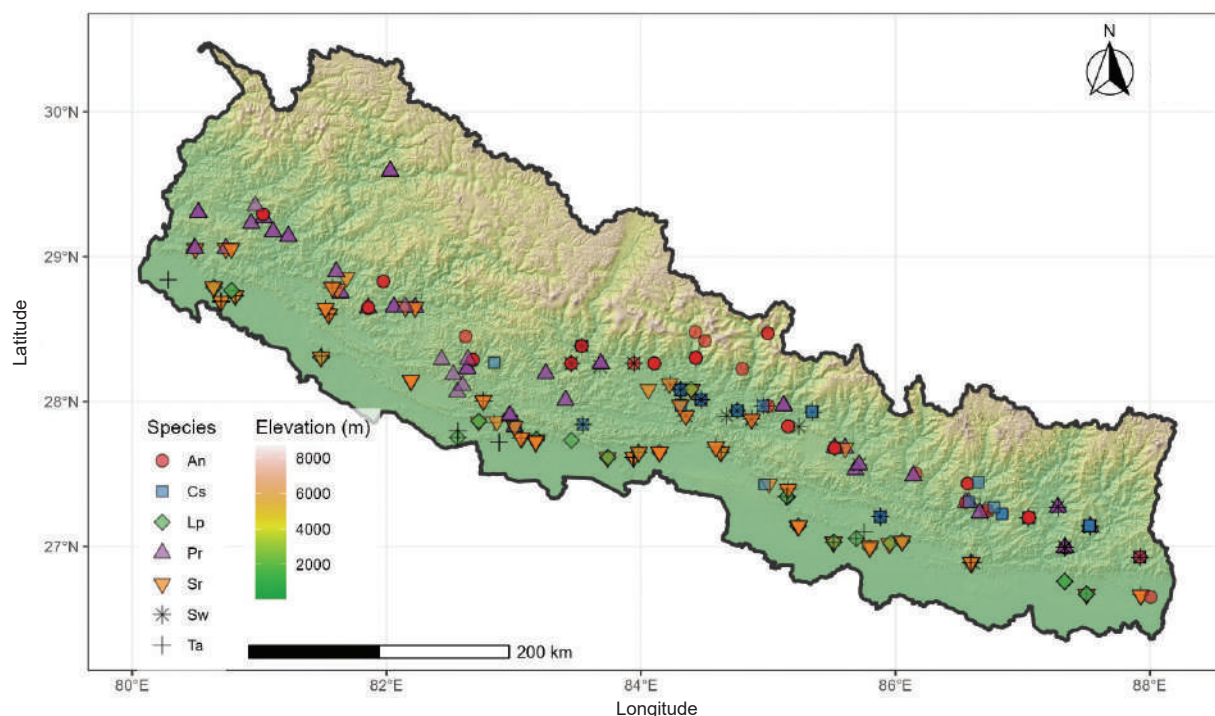


Figure 3: Distribution (location) of sampled trees of seven major tree species throughout Nepal. The acronyms of the species are: An (*Alnus nepalensis*), Cs (*Castanopsis* species), Lp (*Lagerstroemia parviflora*), Pr (*Pinus roxburghii*), Sr (*Shorea robusta*), Sw (*Schima wallichii*) and Ta (*Terminalia alata*).

edges, clearings, or isolated trees) were excluded, as their size and form (stem and crown) likely differ from those of trees in closed-canopy conditions.

- **Tree Condition:** Dead, damaged, defective, or decayed trees were excluded. Specific exclusion criteria included broken tops or crowns by anthropogenic or natural calamities, hollow trunks, diseased, excessively knotty stems, decay, or previous topping.

2.2.6 Selection of Final Sample Trees

Following this initial selection, all the potential samples were grouped into their predefined strata as candidate trees. A random selection was then made from each group for all seven targeted species. The geographical distribution of the final selection was visualized on a map to check for adequate representation across topographical and geographical gradients. Upon identifying a non-representative geographic distribution, the selection process was reiterated to obtain a more representative sample. A total of 489 trees were finally selected for destructive sampling (Figure 4) out of 496 planned trees.

2.3 Field Measurements

Phenology is an important consideration for biomass measurement which is directly linked with the season of field measurement. Due to large species and geographical variation in Nepal, it is difficult to work in the same phenological condition. However, an appropriate time for field work was identified during the dormant season just before leaf shedding. Therefore, the field data was collected in January to March, and December 2023.

The FRTC had developed the “Data Collection Guidelines for the Preparation of the Allometric Equations of Major Tree Species, 2022”. Four



days-long hands-on training and orientation about the data collection guidelines were provided to the team members for

tree measurements and collecting the field level data.

Field data were collected and recorded onsite just before and right after the felling of sample trees. In addition, the data records included the geographical features of sites and sample plots

and individual tree characteristics as explained in the following sections.

2.3.1 Measurements Before Felling Sample Trees

Prior to felling, comprehensive site and stand data were recorded. This involved conducting a detailed inventory of every tree exceeding 5 cm DBH located within a 10-meter radius of each sample tree. Site data such as coordinates, slope, aspect, location, forest type, developmental stage, and other characteristics were recorded. In addition, specific attributes of the sample tree were documented, including its crown metrics (width, height), diameter at breast height (DBH), quality class, and tree height. The DBH of each tree within the plot including the sample tree was measured by D-tape at 0.1 cm accuracy. The total height and crown height of individual trees were also measured at 0.1 accuracy using Vertex IV. All tree characteristics including crown class and quality class of trees were determined based on guidelines.



felled at a standardized position of 30 cm above ground level. Each felled tree was systematically separated into three primary components and data recorded systematically for foliage, stem and branches.

Measurements:

- Diameter Measurement:** Over-bark diameters of stems were measured every 50 cm interval from 0.30 m to 2.3 m above the ground level along the stem followed by 1 m interval up to the tip of the stem (Figure 4) using D-tape at the 0.1 cm precision. When abnormal tree parts were found (swollen, broken, etc.) additional diameter measurements were taken at the beginning, middle and end of the abnormal sections. After debarking, under-bark diameter measurements were taken at exactly the same point and method of overbark measurement. Similarly, over-bark and under-bark diameters of each main and sub-branches were measured from the base of the branches up to top 10 cm diameter at every 1 m interval for large branches (>10 cm). Additional measurements were taken

2.3.2 Measurements After Felling Sample Trees

Following a detailed inspection and recording of sample tree information, the sample trees were

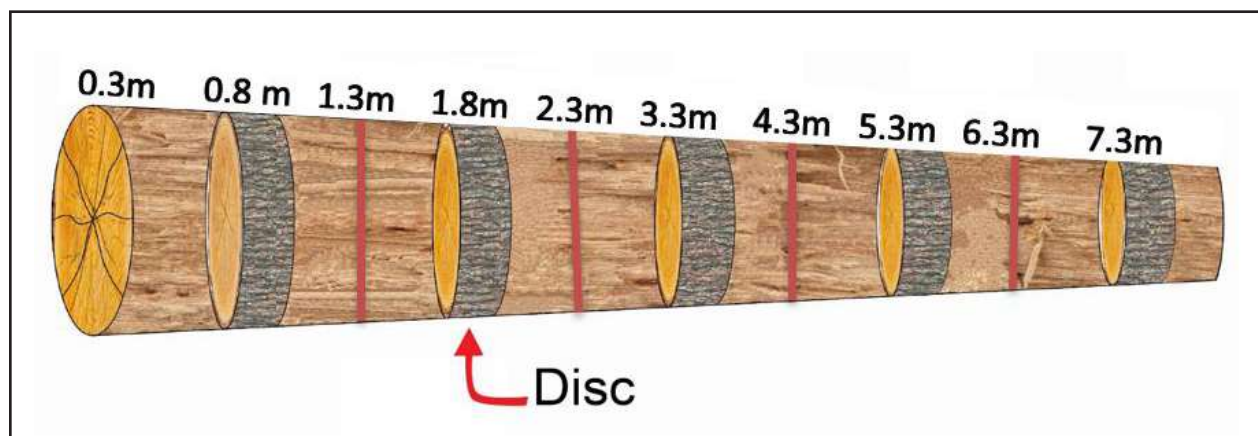


Figure 4: Positions of diameter and disc measurements along the tree trunk. The red line indicates the points where over-bark and under-bark diameters were measured. The disc represents the locations from where discs were extracted for wood density estimation in the laboratory.

at points of deformation, negative taper, or for the precise top 10 cm and 20 cm sections for all the stem branch sections.

- ❑ **Weight Measurement:** All other components were weighed separately in the field. This included the three classes of small branch (<10-7.5 cm over bark



diameter, <7.5-4.5 cm over bark diameter and <4.5 cm over bark diameter), stems of less than 10 cm in diameter (which were also measured diameter and grouped into the three categories as in small branches), all dead biomass, and all the foliage components as leaves, flowers, cone etc.

- ❑ **Volume Calculation:** The volume of each disc was instantly measured in the field via the xylometric method (applying Archimedes' principle) with a precision of



1 cm³. For each disc, both the over-bark and under-bark fresh volume and weight were measured separately to the precisions of 1 cm³ and 1 g, respectively.

- ❑ **Precision:** All diameter (stem and branches), length (stem and branches), and weight measurements (foliage and

small branches) were recorded with a precision of 0.1 cm, 0.1 m, and 0.05 kg, respectively in the field.

Sub-sample Selection

- ❑ **Stem Discs:** Sample discs were collected from every alternate measurement point along the stem, as well as from large branches, as shown in Figure 4, for the determination of volume and moisture content. Over-bark and under-bark fresh volume and fresh weight of the discs were taken as quickly as in the field. The larger disc, greater than 50 cm diameter, was cut in four pieces along the pith in perpendicular alignment. Then, two opposite sub samples of those discs were taken for the laboratory process. All the discs and their bark were weighed at 1g precision.

- ❑ **Branches:** The diameter of each branch and sub-branches were measured at every meter from the base of branches up to the



top 10 cm over-bark diameter and discs were taken for every alternate diameter measurement point as in stem. Moreover, five sample discs were randomly taken from each of the three small-branch diameter classes. Then volume and weight were recorded the same way as other discs. Similarly, the disc of each dead wood group (e.g dead branches classified similar to small branches or large branches defined by diameter), were taken and volume and weight were taken as in other discs. The total number of disc is given in Table 3.

- ❑ **Foliage:** All components of foliage such as leaves, fruit and cones of the whole tree were weighed separately, then a representative sub-sample of 1 kg foliage (leaves and twigs) for less than 50 kg of total foliage

Table 3: Discs measured across different diameter classes (OB). The acronym used for species, refer to Table 1 above.

Species	Over Bark Diameter Class (cm)							Total
	<10	10-19.9	20-29.9	30-39.9	40-49.9	50-59.9	≥60	
An	713	408	154	110	51	31	22	4300
Cs	816	525	146	68	35	20	10	1620
Lp	740	377	135	67	36	10	20	1385
Pr	1217	803	264	188	127	88	56	2743
Sr	1910	1671	562	314	208	142	185	4992
Sw	733	353	147	72	39	21	15	1380
Ta	968	804	266	168	98	60	85	2449
Total	7097	5246	2233	1590	1256	1054	393	18869

and 2 kg for greater than 50 kg foliage was collected after thoroughly mixing all of the foliage. Likewise, 1 kg each of fruits and cones were collected, but in case of un-abundant samples such as for premature trees, the sample was smaller.



a air-dried weight. The size, weight and porosity of the disc and bark were highly heterogeneous. The weight of the disc ranged from 2 g to >40 kg (50 cm diameter). Therefore, the samples were put in room temperature from five months to one and half years depending on size and time available for oven.

- ❑ **Oven Drying:** Following air drying, samples were oven-dried to remove all residual moisture. The oven drying of samples started from the small bark, small disc to larger discs. Delicate components like foliage were dried at 70°C to prevent combustion, while all other samples (wood discs, bark) were dried at 105°C (FAO, 1997, Donegan *et al.* 2014) in FRTC lab used Faithful Laboratory Oven Drying with 6 shelves (Model WGL-625B, Power: 5KW, Voltage: 380V, Frequency:50Hz, Temp. Range: RT+10~300C). Samples of similar weight, and nature of drying species were put into the oven at a time. Samples were weighed repeatedly by using a digital weighing machine during this process until a constant weight was achieved. Then, the



2.4 Laboratory Process

All collected samples, including foliage, fruits, cones, stem and branch discs, were transported to the Forest Research and Training Centre (FRTC) laboratory, Kathmandu, for moisture content analysis and biomass measurement. The process involved into two drying phases:

- ❑ **Air Drying:** Samples were first placed in FRTC lab at room temperature and repeatedly weighed until their mass stabilized, indicating they had reached



final oven-dry weight was recorded using a digital scale with a precision of 1 gram. The days required to complete the oven dry process varied from 24 hrs to a more than a week depending on size and nature of species.

Due to the large sample size of disc, including large discs, it was not possible for drying in the medium-sized oven in FRTC lab, therefore we used a commercial kiln to dry the sub-samples operated by the Ambika Plywood Factory in Banepa, Kabhrepalanchowk and the large kiln using heat from the boilers was used. Similar to the FRTC lab, the samples were repeatedly weighed until to gain constant weight.



To ensure data quality and consistency between the FRTC and commercial ovens, a quality control procedure was implemented: 30 samples of each species were dried in both ovens in a cross-checking method. The results from both

facilities showed similar results, confirming their equivalence and eliminating the need for a correction factor in the data.

2.5 Data Checking and Cleaning

All collected data underwent a rigorous quality checking process through visualizing all variables. Measurements were thoroughly checked and cross-referenced to ensure internal consistency; for instance, double entries, missing values of variables such as ob, ub, length, weight etc and detect the outlier measurements of any



variables. Checked the data repeatedly and if necessary verified through the field forms and corrected the data. Similarly, if any error or missing data was found the suitable value was imputed using statistical methods as mean

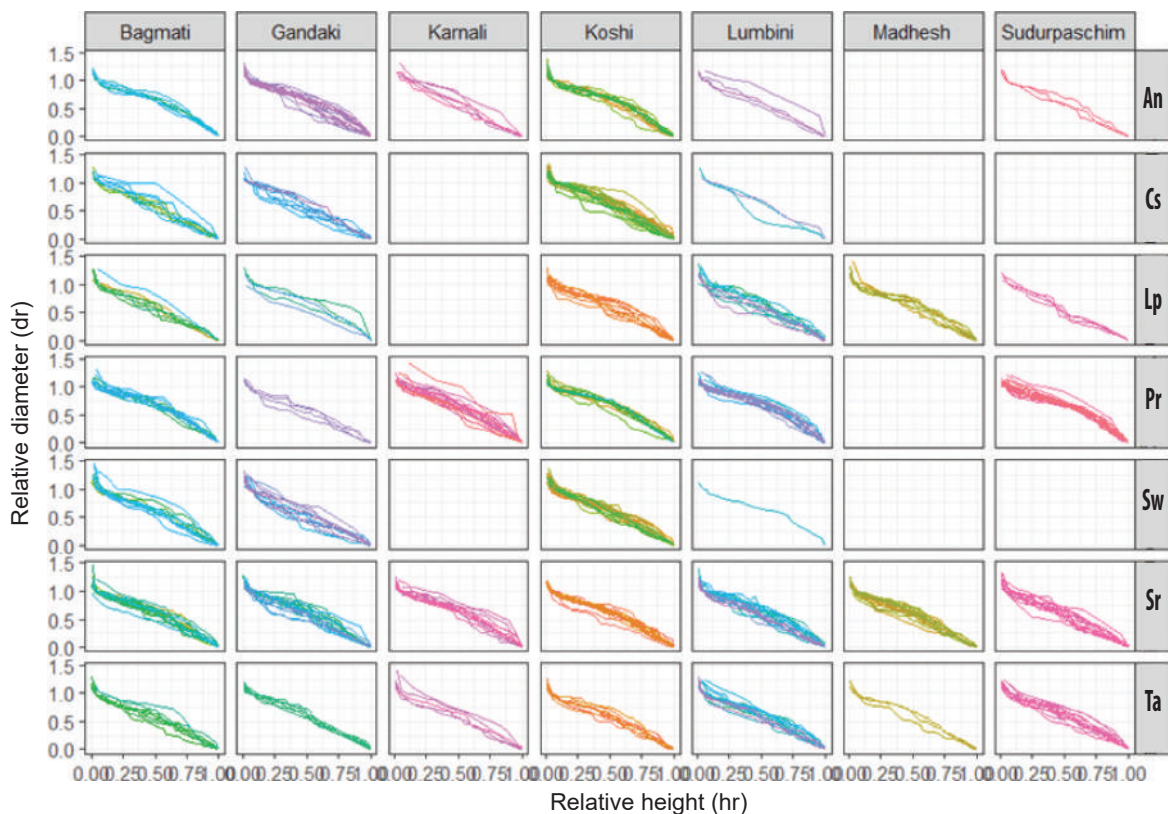


Figure 5: The visualization of province and specieswise height diameter ratio to detect possible error and outliers.

and trend analysis. Ob/Ub ratio, and volumes were validated through visualization using scatterplots, taper curves, over-bark, under-bark ratio, trend of disc density and height-diameter (H-D) relations as in Figure 5.

The outliers that are not frequent in the forest, alone within a diameter class and would influence the models were removed from the dataset. A total of 13 trees belonging to all major species were excluded in model fitting and trees used for model fitting as shown in Figure 6. The detail of sample trees used in model fitting are given in Annex II.

2.6 Data Processing

After the field measurement of standing and felled trees, we calculated the volume, biomass and density of the individual sample species as described below.

2.6.1 Volume Calculation

Smalian's formula (Equation 1) was used to calculate the volume of all cross-sectional logs except the tip portion of the stem. The conical formula (Equation 2) was used to estimate the volume for the topmost log of the stem (tip portion).

$$v_{li} = \pi \frac{(d_{i1})^2 + (d_{i2})^2}{2 \times 4} * l_i \dots\dots\dots(1)$$

where,
 v_i is the volume of having log length (l_i), lower (d_1) and upper sections (d_2) diameters.

$$v_{lt} = \pi \frac{(d_t^2)}{12} * l_t \dots\dots\dots(2)$$

Where,
 v_{lt} is the volume of the cone-shaped top log of base diameter (d_t).

These n individual cross-sectional logs volumes were then summed to determine the total volume for an entire tree stem volume as:

$$V = \sum_{i=1}^n v_{li} + v_{lt} \dots\dots\dots(3)$$

All the volume was calculated above the stump height (0.3m from ground level). The volume of stump was calculated by cylindrical formula (Equation 4) and given in Annex II.

$$V = \frac{d^2}{4} \times L \dots\dots\dots(4)$$

Where,
 V = Stump volume
 d = diameter of trees above 30 cm ground level
 L = length of log = 30 cm

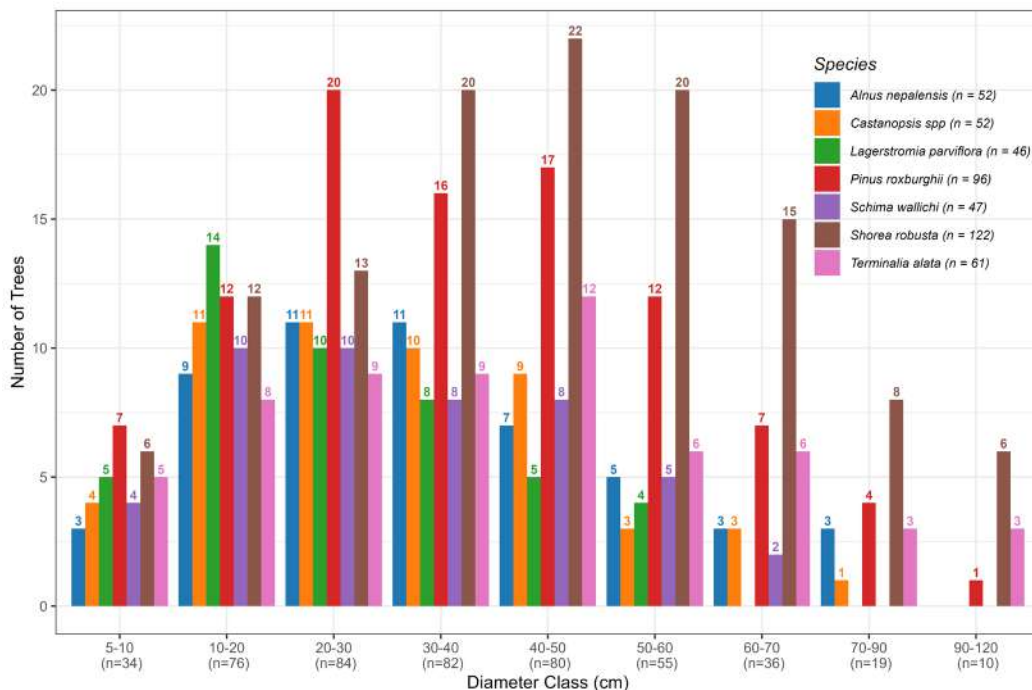


Figure 6: Distribution of sample trees according to the diameter classes by species.

2.6.2 Density Estimation

To characterize the physical properties of the disc and its components, basic density was estimated as the ratio of dry mass to fresh volume. Separate calculations were performed for the entire wood disc, the bark, and the summed at last.

The basic wood density and airdried wood density was calculated for each individual trees and averaged each dia-class of 10 cm interval. Then mean was calculated giving equal weightage for all dia-class.

Density of Disc Wood (Without Bark)

$$P_{\text{wood}} = \frac{D_{\text{wood}}}{V_{\text{wood}}} \dots\dots\dots (5)$$

P_{wood} : Density of disc wood (without bark)

D_{wood} : Dry mass of wood disc (without bark)

V_{wood} : Fresh volume of wood disc (without bark)

Density of Disc Bark

$$P_{\text{bark}} = \frac{D_{\text{bark}}}{V_{\text{bark}}} \dots\dots\dots (6)$$

P_{bark} : Density of disc bark

D_{bark} : Dry mass of bark

V_{bark} : Fresh volume of bark

2.6.3 Biomass Estimation

The total above-ground biomass (leaving the stump 30 cm above ground level) of the tree was calculated by summing the biomass of all individual components (stem, branches, foliage, fruits, cones).

The biomass of each component was calculated as:

Biomass of Disc

$$B_{\text{disc}} = (F_{\text{bark}} \times P_{\text{bark}}) + (F_{\text{wood}} \times P_{\text{wood}}) \dots (7)$$

F_{bark} : Fresh mass of disc bark

P_{bark} : Density of disc bark

F_{wood} : Fresh mass of disc wood

P_{wood} : Density of disc wood

Biomass of Logs

$$B_{\text{log}, i} = P_{\text{disc } i} \times V_{\text{log}, i} \dots\dots\dots (8)$$

$P_{\text{disc } i}$: Density of disc i

$V_{\text{log}, i}$: Volume of log corresponding to disc i

Biomass of Stem

$$B_{\text{stem}} = \sum_i B_{\text{log}, i} \dots\dots\dots (9)$$

$B_{\text{log}, i}$: Biomass of log i

Biomass of Large Branch

$$B_{\text{large branch}} = \sum_i B_{\text{branch log}, i} \dots\dots\dots (10)$$

$B_{\text{branch log } i}$: Biomass of branch log i

Biomass of Small Branches

$$B_{\text{small branch}} = \sum_i F_{\text{small}, i} \left(\frac{1}{n} \sum_j \frac{D_{\text{disc}, j}}{F_{\text{disc}, j}} \right) \dots (11)$$

$F_{\text{small}, i}$: Fresh weight of small branch i

$D_{\text{disc}, j}$: Dry weight of disc sample j

$F_{\text{disc}, j}$: Fresh weight of disc sample j

n : Number of disc samples

Total Biomass of Branch

$$B_{\text{branch}} = \sum_i B_{\text{large branch}, i} + \sum_i B_{\text{small branch}, i} (12)$$

$B_{\text{large branch}, i}$: Biomass of large branch i

$B_{\text{small branch}, i}$: Biomass of small branch i

Biomass of Leaves and Twigs

$$B_{\text{lt}} = F_{\text{lt}, \text{total}} \times \frac{D_{\text{lt}, \text{sample}}}{F_{\text{lt}, \text{sample}}} \dots\dots\dots (13)$$

$F_{\text{lt}, \text{total}}$: Total fresh weight of leaves and twigs

$D_{\text{lt}, \text{sample}}$: Dry weight of leaves–twigs sample

$F_{\text{lt}, \text{sample}}$: Fresh weight of leaves–twigs sample

Biomass of Fruit/Cone/Flower

$$B_{\text{fct}} = F_{\text{fct}, \text{total}} \times \frac{D_{\text{fct}, \text{sample}}}{F_{\text{fct}, \text{sample}}} \dots\dots\dots (14)$$

$F_{fct,total}$: Total fresh weight of fruits, cones, or flowers

$D_{fct,sample}$: Dry weight of sample fruit/cone/flower

$F_{fct,sample}$: Fresh weight of sample fruit/cone/flower

Biomass of Foliage

$$B_{foliage} = B_{lt} + B_{fcf} \dots\dots\dots (15)$$

B_{lt} : Biomass of leaves and twigs

B_{fcf} : Biomass of fruits, cones, or flowers

Total Biomass of Tree

$$B_{tree} = B_{stem} + B_{branch} + B_{foliage} \dots\dots\dots (16)$$

Where,

B_{stem} : Biomass of stem

B_{branch} : Biomass of branches

$B_{foliage}$: Biomass of foliage

The biomass given by models exclude the stump biomass and calculated separately and given in Annex II.

2.7 Predictive Model Development

From the data obtained in section 2.3, we constructed predictive models for volume and biomass of individual trees. The models for volume consisted of three equations each one for total stem volume (over bark), the top 10 cm diameter under-bark volume and the top 20-cm diameter under bark volume of the stem. We fitted six forms of model and evaluated (Table 4). We have selected one as the best among these six models for the volume prediction. The volume of branches were calculated as ratio of total stem volume for simplicity and applicability. For simplicity we only used DBH and total height of individual trees as explanatory variables assuming these variables are the good predictors regardless of different bio and geographical site conditions.

Table 4: Examined model forms for volume

Model no.	Candidate Models	Reference
M1	$V_i = a + b \cdot D$	Picard <i>et al.</i> 2012
M2	$V_i = a + b \cdot D + c \cdot H$	Picard <i>et al.</i> 2012
M3	$V_i = a + b \cdot D^2 \cdot H$	Spurr, 1952
M4	$V_i = a \cdot D^b$	Brown, 1997
M5	$V_i = a \cdot D^b \cdot H^c$	Chave <i>et al.</i> 2005
M6	$V_i = a \cdot (D^2 \cdot H)^b$	Huxley and Teissier, 1936

V_i = Volume {Total stem volume (ob), Volume up to top 10 cm diameter (ub), Volume up to top 20 cm diameter (ub)}, in m^3 .

Likewise, we constructed models for total biomass and stem biomass of individual tree species. We fit five model forms (Table 5, Picard *et al.*, 2012) aiming to select one that fits the best based on model selection criteria (section 2.8).

Table 5: Examined model forms for biomass

Model number	Candidate Models
M7	$B_i = a \cdot D^b$
M8	$B_i = a \cdot (D^2 H)^b$
M9	$B_i = a \cdot D^b \cdot H^c$
M10	$B_i = a \cdot ((D^2 H \rho))^b$
M11	$B_i = a \cdot (D^2 H)^b \cdot \rho^c$

- a, b, c, d = parameters of the candidate models
- e = random error
- B_i = Biomass (Total Biomass, Stem Biomass) in Kg.
- V_i = Volume {Total stem volume (ob), Volume up to top 10 cm diameter (ub), Volume up to top 20 cm diameter (ub)}, in m^3 .
- D = Diameter at breast height, in cm
- H = Total height of the trees, in meter

2.8 Model Selection

After fitting the models, parameter estimates were obtained and tested for statistical significance. Model adequacy was assessed through residual analysis and by evaluating several goodness of fit criteria, including adjusted R^2 (only for linear models) root mean square error (RMSE), Akaike information criterion (AIC), and mean bias (MB). These statistics were computed as follows:

$$AIC = 2k - 2\ln(\hat{L})$$

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

$$MBE = \frac{1}{n} \sum_{i=1}^n (y_i - \hat{y}_i)$$

Both RMSE and MBE were calculated for fitted values (within sample performance) and predicted values (out of sample validation). This dual evaluation allowed us to assess not only how well the models explained the observed data but also their predictive reliability.

To address heteroscedasticity, a power variance function was applied using DBH as the variance covariate. This approach models the residual variance as a power function of DBH, allowing larger trees, which typically exhibit greater variability, to have proportionally larger residual variance. The variance structure is defined as $\text{Var}(\epsilon_i) = \sigma^2 |\text{DBH}_i|^{2\delta}$, where δ is a parameter estimated from the data. This weighting improves parameter estimation and stabilizes the residuals.

All the analysis and model fitting were done in R programming environment 4.2 (R core Team 2025) the “nlme” function (Pinheiro *et al.*, 2025) was used for model fitting. Maximum likelihood method was used for model fitting and the alpha level of significance was assumed to be at 0.05 for all the necessary tests. The best candidate model was selected largely based on AIC value. Moreover, RMSE and MBE values were also taken into consideration when selecting the model as appropriate.

2.9 Model Validation

Leave one out cross validation (LOOCV) method was applied to validate all the suggested models. Moreover, a reference dataset was used to test the robustness of the fitted models. An independent dataset collected by the provincial Forest Research and Training Centre (FRTC), Godawari, consisting of 88 *A.nepalensis* trees, collected in 2020 for the purpose of developing local volume tables, was employed to validate

total stem volume predictions. Similarly, 48 sample trees data of Banke district from Subedi *et al.*, 2021 were used to model validation of *S. robusta*. These results were compared against historical models developed by Sharma & Pukkala (1990) to evaluate improvements in accuracy and applicability.

2.10 Quality Assurance

- Field activities were jointly verified by officials from the Forest Research and Training Centre (FRTC) and the project management team across nearly all sampling sites, under the coordination of the technical committee. Randomly selecting the five percent sample trees, the technical committee verified field measurement. All collected data underwent systematic checks, validation, and, where necessary, refinement by external experts.
- The volume of the randomly sampled discs were re-measured at the FRTC laboratory prior to formal acceptance of both the data and physical samples from the service providers.
- To cross-validate wood density estimates, a total of 115 discs were re-weighed at 1-gram accuracy in the FRTC laboratory. These included 20 discs each of *Shorea robusta* and *Terminalia alata*, and 15 discs each for the remaining five species. In addition, 117 rectangular wood samples (10 × 2 × 2 cm) of *S. robusta*, originally collected in air-dry condition for mechanical strength testing at the FRTC UTM laboratory, were used to further validate density estimates. Densities obtained from these independent measurements were compared with density values derived from whole-disc samples of *S. robusta*.
- Preliminary findings were presented to senior officials of the Ministry of Forests and Environment during a dedicated results-sharing workshop. Their feedback and recommendations were documented and incorporated into the analysis wherever feasible.



3. Results

3.1 Allometric Equations for Volume

3.1.1 Total Stem Volume Over-bark

Linear and non-linear regression models were fitted to estimate the stem volume up to the top 10 cm (under bark), top 20 cm (under bark), diameter and the entire tree stem (over bark) volume of seven tree species separately. For an easy application, DBH and height only were used as predictors for each model. The best fit model for each species was selected based

0.08 (*S. wallichii*) to highest 0.41 (*R. robusta*). The fit statistics of suggested models for each species is given below (Table 6) and fit statistics and their parameters of all the tested models of each species are also given in Annex III so that the user can use other models based on their requirements.

The residuals of all the selected models for total stem volume, was not observed heteroscedasticity and found randomly scattered around the 0 residuals line. Moreover, the

Table 6: Summary statistics of best fitted model for total stem volume (over bark) for all seven species (n: number of sampled trees, a, b and c indicate model parameters).

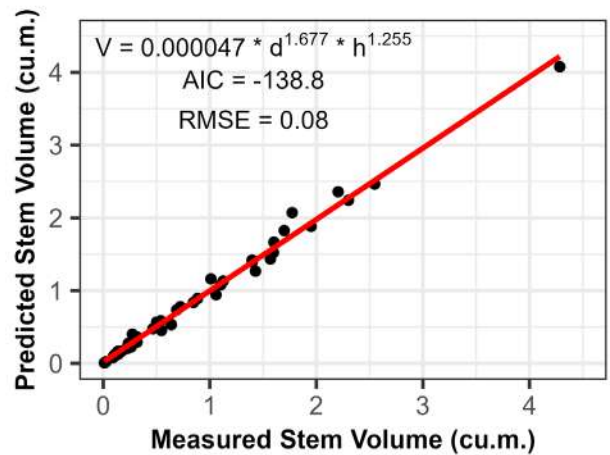
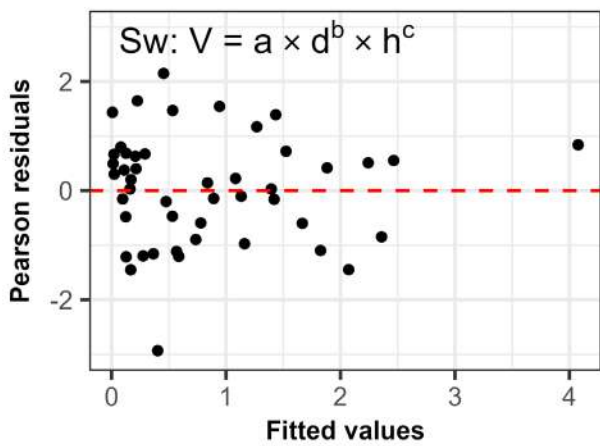
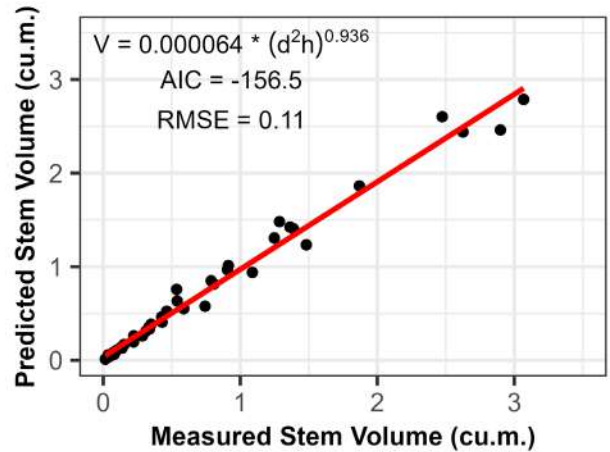
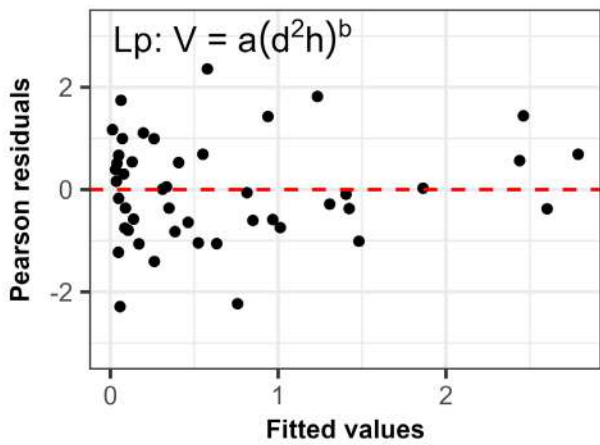
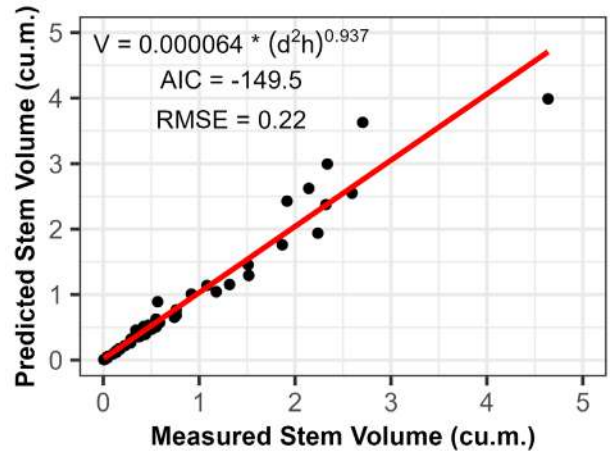
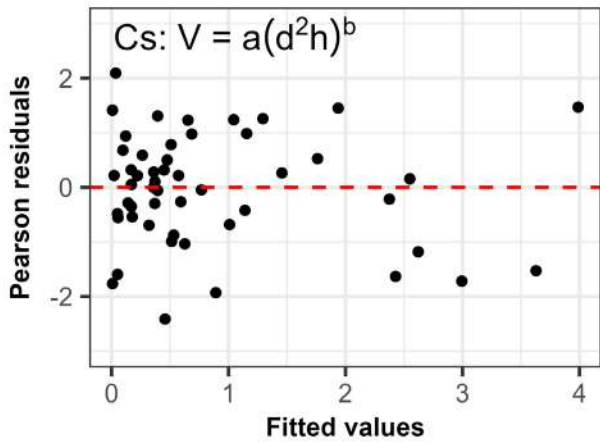
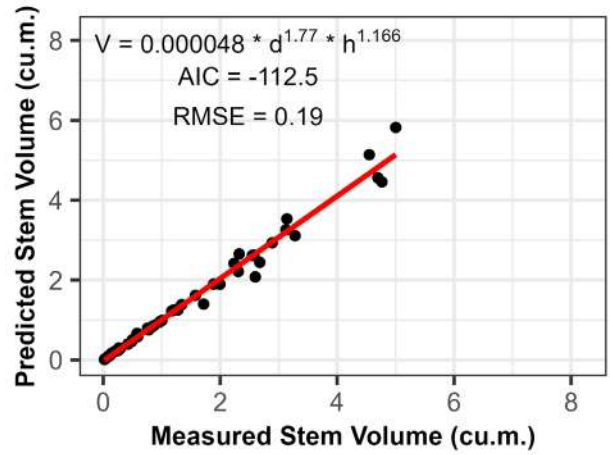
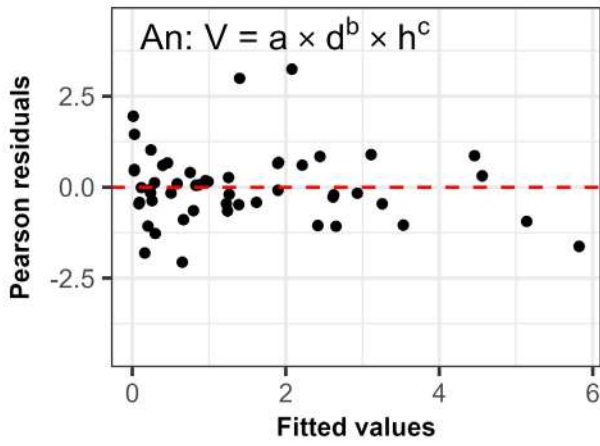
Total stem volume (OB)	Equation	n	a	b	c	AIC	RMSE	Adj R ²
<i>Alnus nepalensis</i>	$V = a * d^b * h^c$	52	0.000048	1.769901	1.165658	-112.50	0.190	0.98
<i>Castanopsis</i> spp.	$V = a * (d^2h)^b$	52	0.000064	0.936534	-	-149.5	0.222	0.94
<i>Lagerstroemia parviflora</i>	$V = a * (d^2h)^b$	46	0.000064	0.936459	-	-156.50	0.110	0.98
<i>Pinus roxburghii</i>	$V = a * (d^2h)^b$	96	0.000058	0.957300	-	-232.0	0.25	0.98
<i>Shorea robusta</i>	$V = a * (d^2h)^b$	122	0.000059	0.948535	-	-131.9	0.41	0.98
<i>Schima wallichii</i>	$V = a * d^b * h^c$	47	0.000047	1.677002	1.254950	-138.80	0.080	0.99
<i>Terminalia alata</i>	$V = a * (d^2h)^b$	61	0.000070	0.928364	-	-124.0	0.27	0.99

Note: All the parameter were significant at 0.05% significance level.

on above mentioned fit statistics. For over-bark total stem volume, model (M6: $V_i = a * (d^2h)^b + e$) was found best performing model for the most of the species except *A. nepalensis* and *S. wallichii* where Model 5 (M5: $V_i = a * D^b * H^c + e$) was found the best performer. All the models have less than 0.5 RMSE ranging from lowest

observed versus predicted volume shows the good predictability of the selected models. All other models predict exactly the same measured values except the *L. parviflora* (Lp) that is a little bit under estimates (Figure 7). The detailed fit statistics and residuals of all the tested models for total stem volume are given in Annex III.





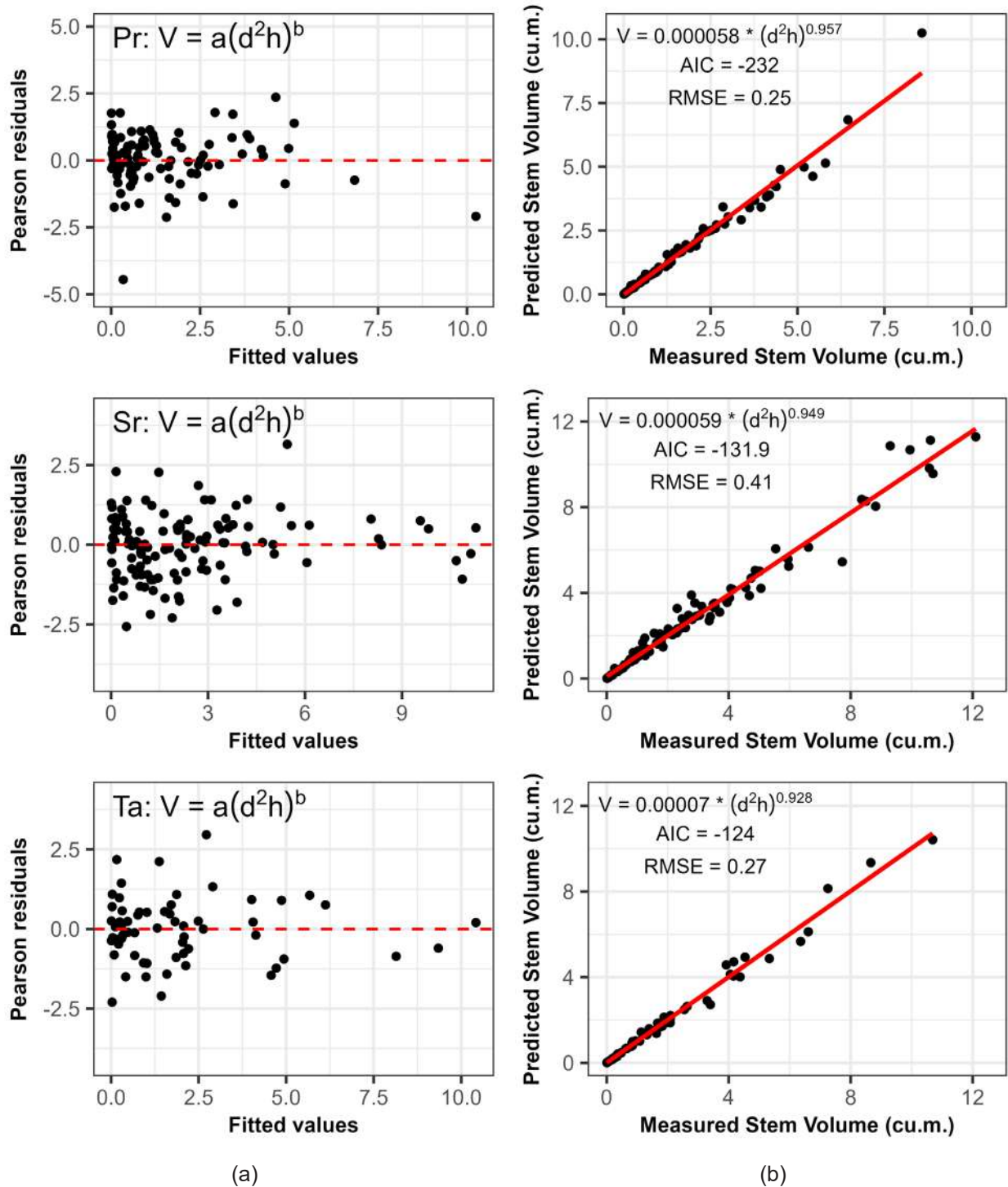


Figure 7: Graphical presentation of residuals and predicted values of selected models for total stem volume of all seven species (a) Residual distribution along the fitted values of selected models and (b) Measured vs predicted volume (cu. m.) For tree code (An, Cs, Lp, Sw, Pr, Sr, Ta) refer Table 1.

3.1.2 Under-bark Stem Volume up to Top 20cm Over-bark Diameter

This is considered the true volume of timber. As in the total stem volume, the UV stem volume up to top 20 cm diameter was also suggested model M6 ($V = a * d^b * h^c + e$) for *A. nepalensis* and *S. wallichii* and M5 ($V = a * (d^2h)^b$) for all other species. The RMSE of all species was found less than 0.5 with highest in *S. robusta* to lowest *S.*

wallichii (Table 7). This indicates there might be large variation in volume or stem structure mostly in larger diameter. The detail parameter and figure of residuals of all other tested models of each species is given to Annex IV. The number of observations (n) is reduced because we removed all the smaller sample trees that do not yield the timber of minimum 20 cm diameter of that species.

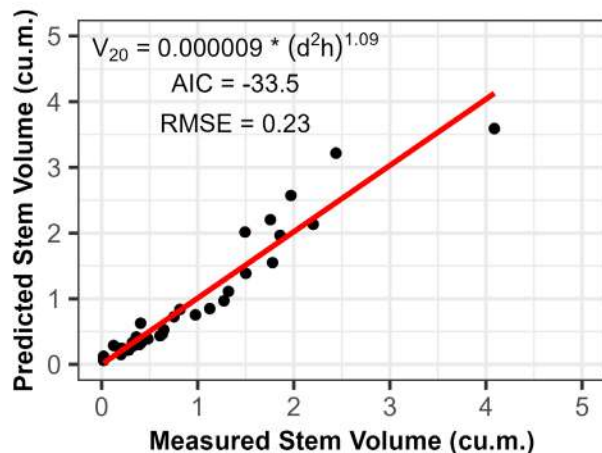
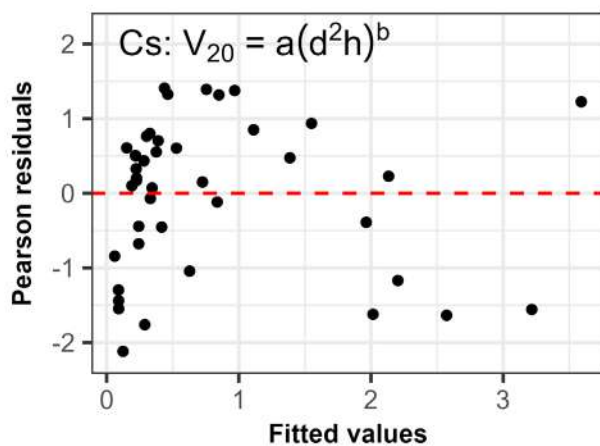
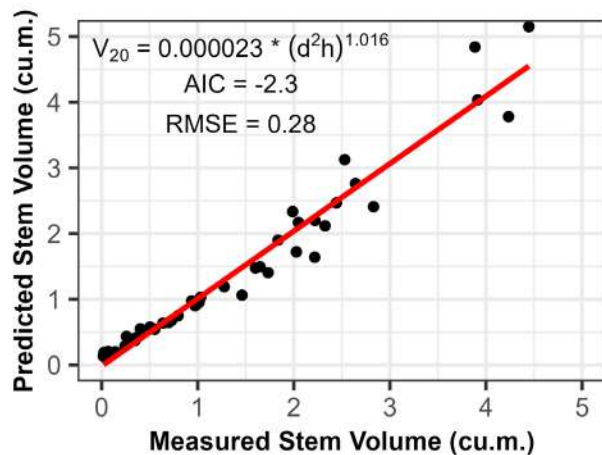
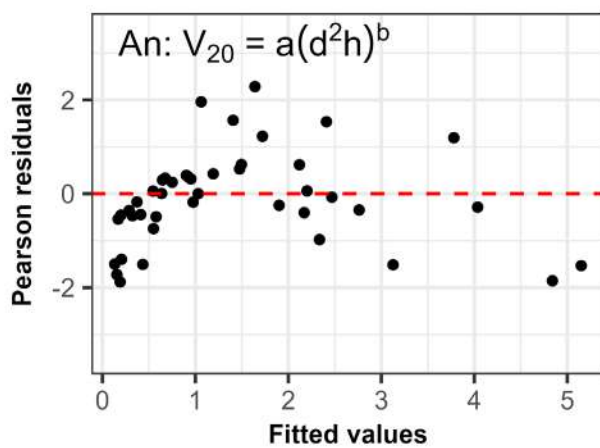
Table 7: Summary statistics of best fitted model for stem volume (under bark) up-to top 20 cm diameter. (n: number of sampled trees)

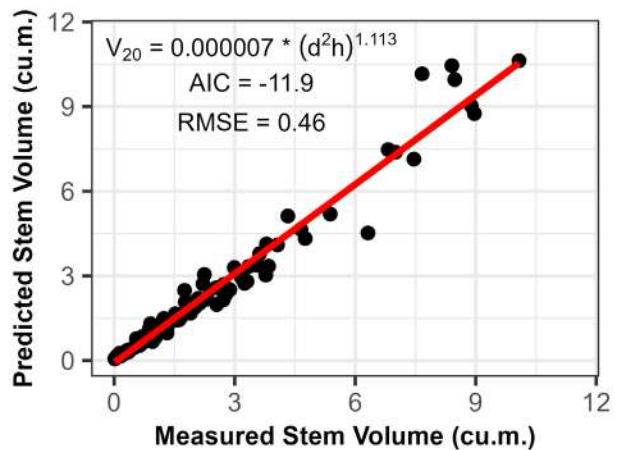
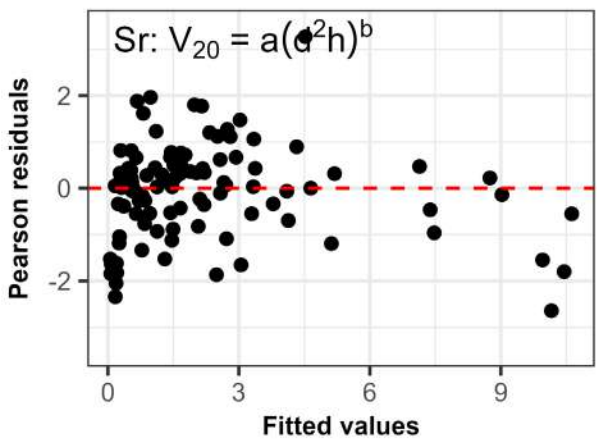
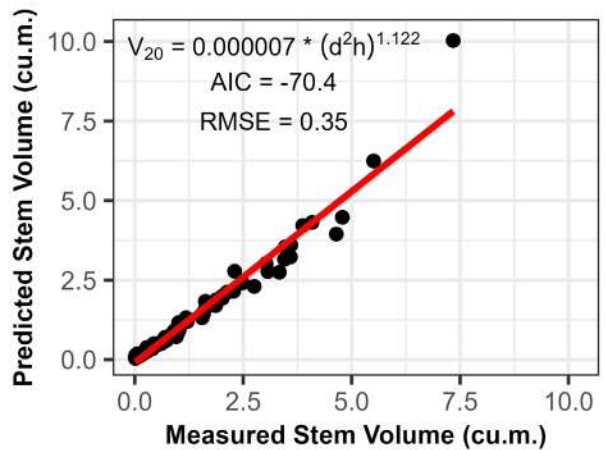
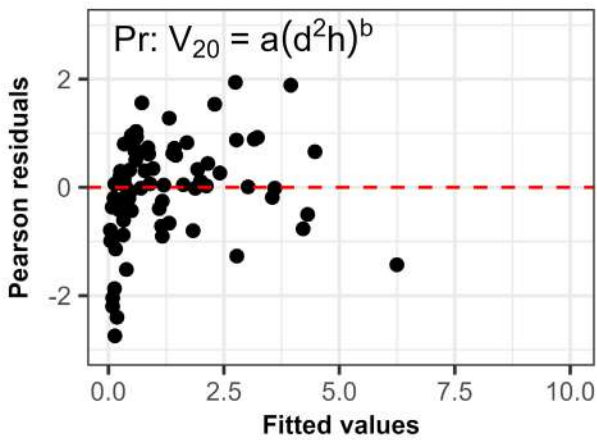
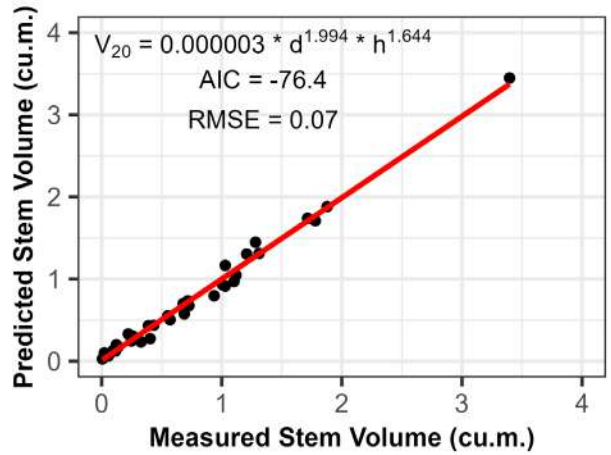
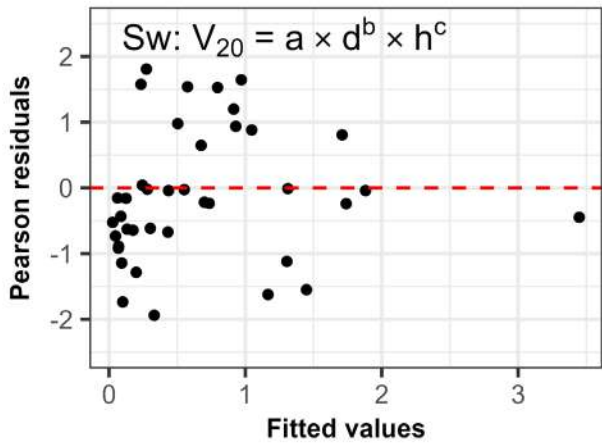
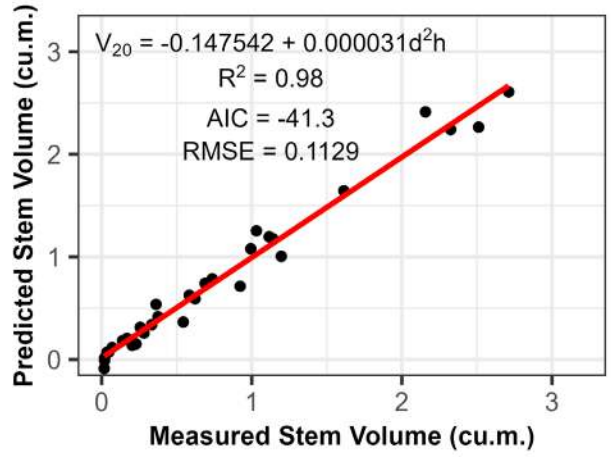
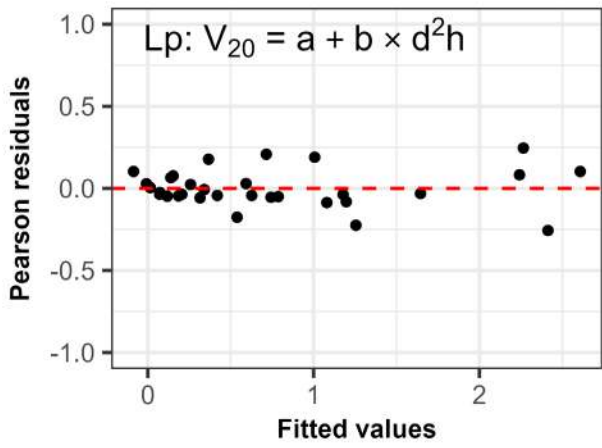
Stem Volume top 20(ub)	Equation	n	a	b	c	AIC	RMSE	Adj R ²
<i>Alnus nepalensis</i>	$V = a * (d^2h)^b$	43	0.000023	1.016204	-	-2.30	0.28	0.94
<i>Castanopsis</i> spp.	$V = a * (d^2h)^b$	42	0.000009	1.089575	-	-33.5	0.230	0.92
<i>Lagerstroemia parviflora</i>	$V = a + b (d^2h)$	31	-0.147542	0.000031	-	-41.26	0.11	0.98
<i>Pinus roxburghii</i>	$V = a * (d^2h)^b$	82	0.000007	1.121720	-	-70.4	0.35	0.94
<i>Shorea robusta</i>	$V = a * (d^2h)^b$	107	0.000007	1.113125	-	-11.9	0.46	0.96
<i>Schima wallichii</i>	$V = a * d^b * h^c$	39	0.000003	1.994043	1.644049	-76.9	0.070	0.99
<i>Terminalia alata</i>	$V = a * (d^2h)^b$	53	0.000010	1.074116	-	-12.9	0.34	0.97

Note: All the parameter were significant at 0.05% significance level.

The fitted values against the residuals shows all the models are acceptable. Based on the predictability of the models, all the models were predicted to have the same volume as in measured volume except in the case of *P.*

roxburghii and *S. robusta* the predicted volume is slightly overestimated in larger diameter classes (Figure 8). The graphical and fit statistics of all the tested models were given in Annex IV.





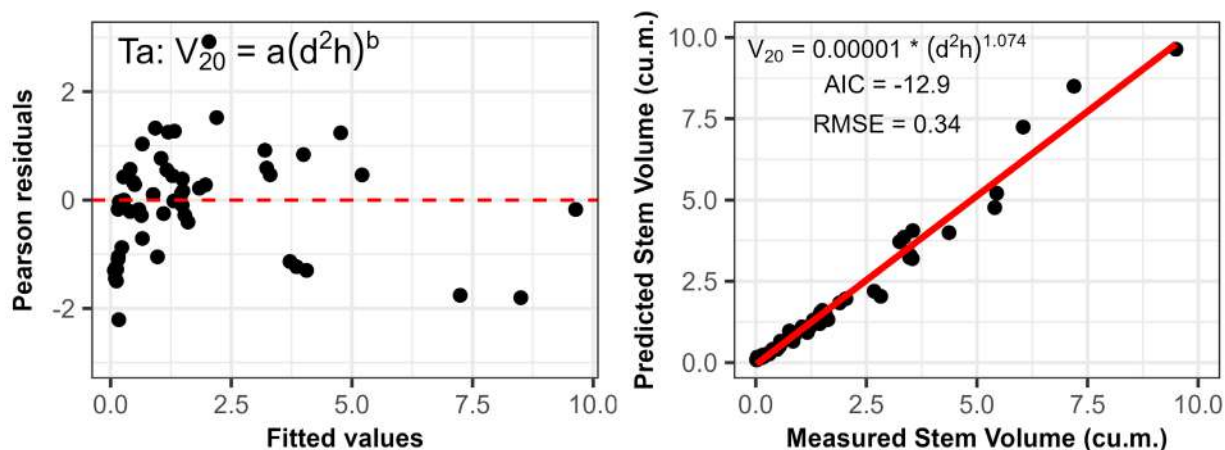


Figure 8 : Graphical presentation of residuals of selected models for stem volume up to top 20 cm diameter of all seven species (a) Residual distribution along the fitted values of selected models and (b) Observed vs predicted volume (cu. m.). For tree code (refer 1). For tree code (An, Cs, Lp, Sw, Pr, Sr, Ta) refer Table 1.

3.1.3 Under-bark Stem Volume up to Top 10 cm over-bark diameter

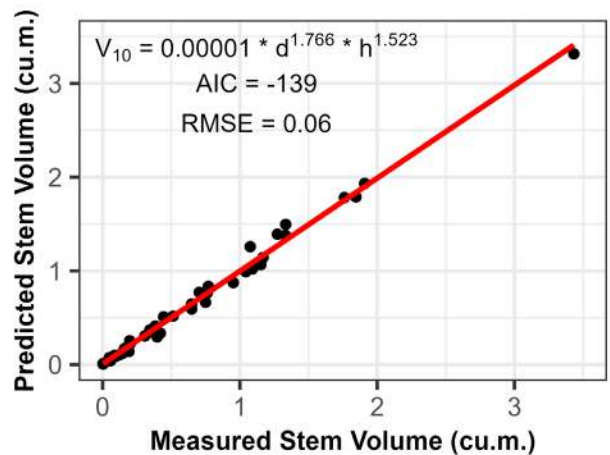
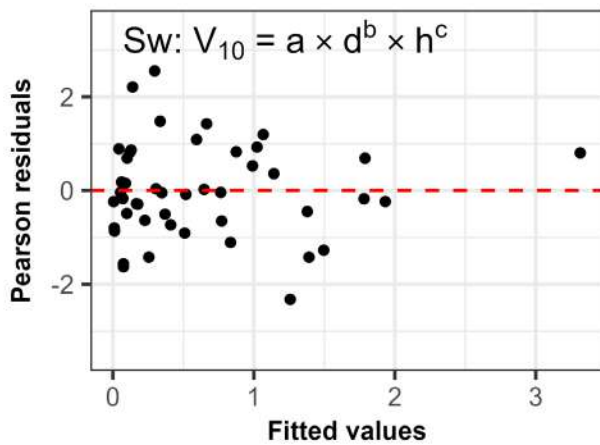
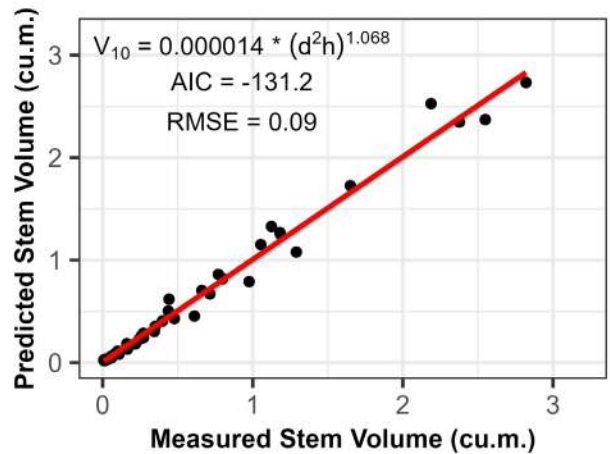
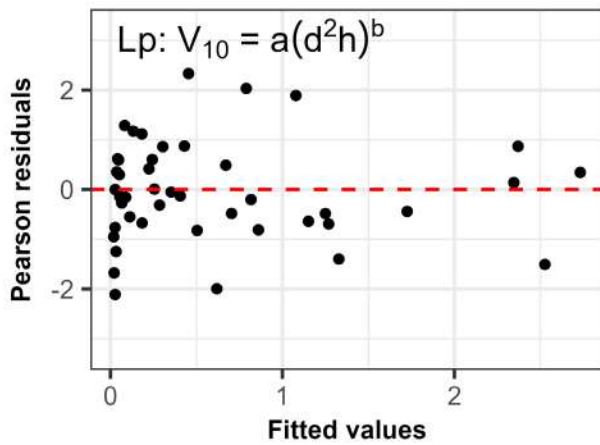
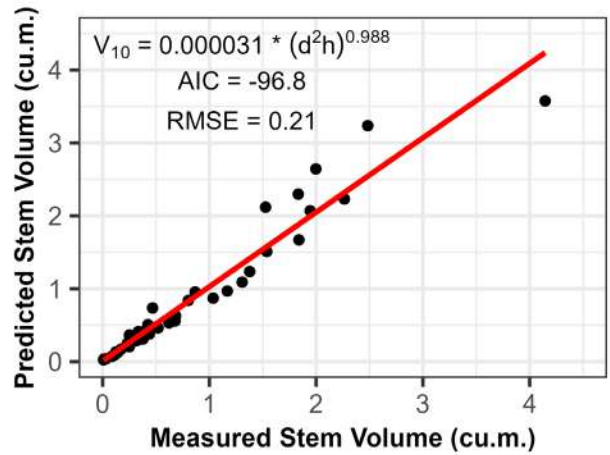
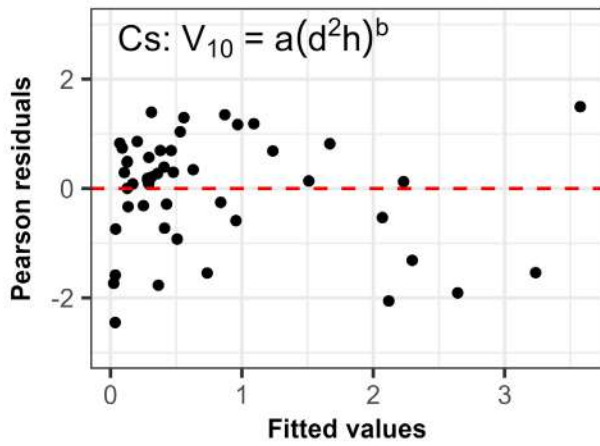
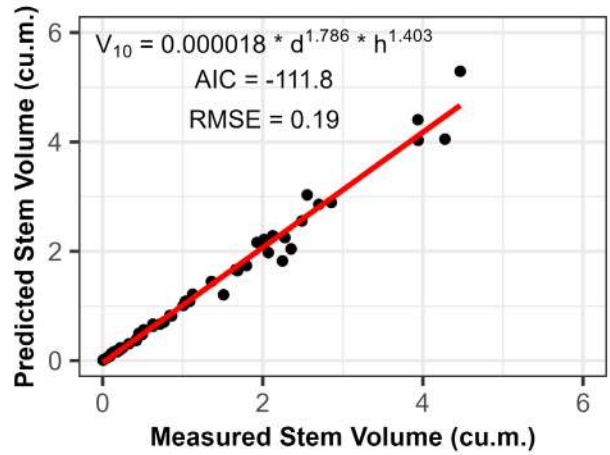
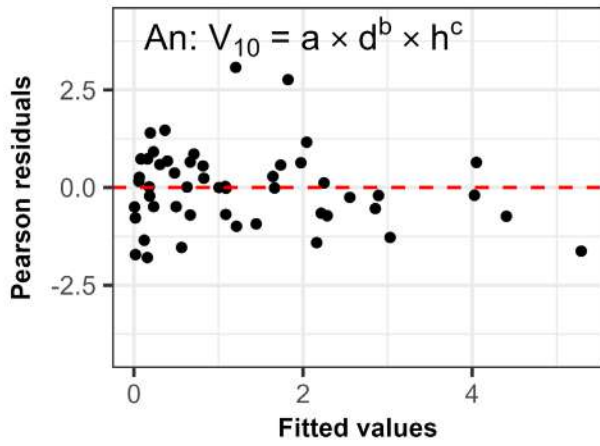
Alnus, *Shorea* and *Schima* has best fit the model 6 ($V = a * d^b * h^c$) and other species best fit the model 5 ($V = a * (d^2h)^b$). Almost all species show the lowest RMSE compared to the total stem volume model and up to the top 20 cm diameter volume models of corresponding species. The lowest RMSE found in *L. parviflora* (0.09) and highest in *R. robusta* (0.39) the detail of statistics is given in Table 8.

All the residual plots show the acceptable pattern of error distribution throughout the range. Although, *Alnus* and *Pinus* are slightly overestimated in higher diameter size classes, all other species show good predictability based on observed and predicted volume (Figure 9). In addition, all the observations lie around the fitted lines of measured vs predicted stem volume. The details of tested models are given in Annex V.

Table 8: Summary statistics of best fitted model for stem volume (under bark) up to 10 cm top diameter

Species	Equation	n	a	b	c	AIC	RMSE	Adj R ²
<i>Alnus nepalensis</i>	$V = a * d^b * h^c$	51	0.000018	1.785698	1.403011	-111.80	0.190	0.97
<i>Castanopsis</i> spp.	$V = a * (d^2h)^b$	49	0.000031	0.987658	-	-96.8	0.210	0.93
<i>Lagerstroemia parviflora</i>	$V = a * (d^2h)^b$	44	0.000014	1.068129	-	-131.20	0.090	0.98
<i>Pinus roxburghii</i>	$V = a * (d^2h)^b$	94	0.000014	1.064049	-	-208.5	0.29	0.96
<i>Shorea robusta</i>	$V = a * d^b * h^c$	119	0.000011	1.960877	1.308190	-109.70	0.39	0.97
<i>Schima wallichii</i>	$V = a * d^b * h^c$	46	0.000010	1.765752	1.523197	-139.0	0.06	0.99
<i>Terminalia alata</i>	$V = a * (d^2h)^b$	59	0.000021	1.013348	-	-88.6	0.29	0.98

Note: All the parameter were significant at 0.05% significance level.



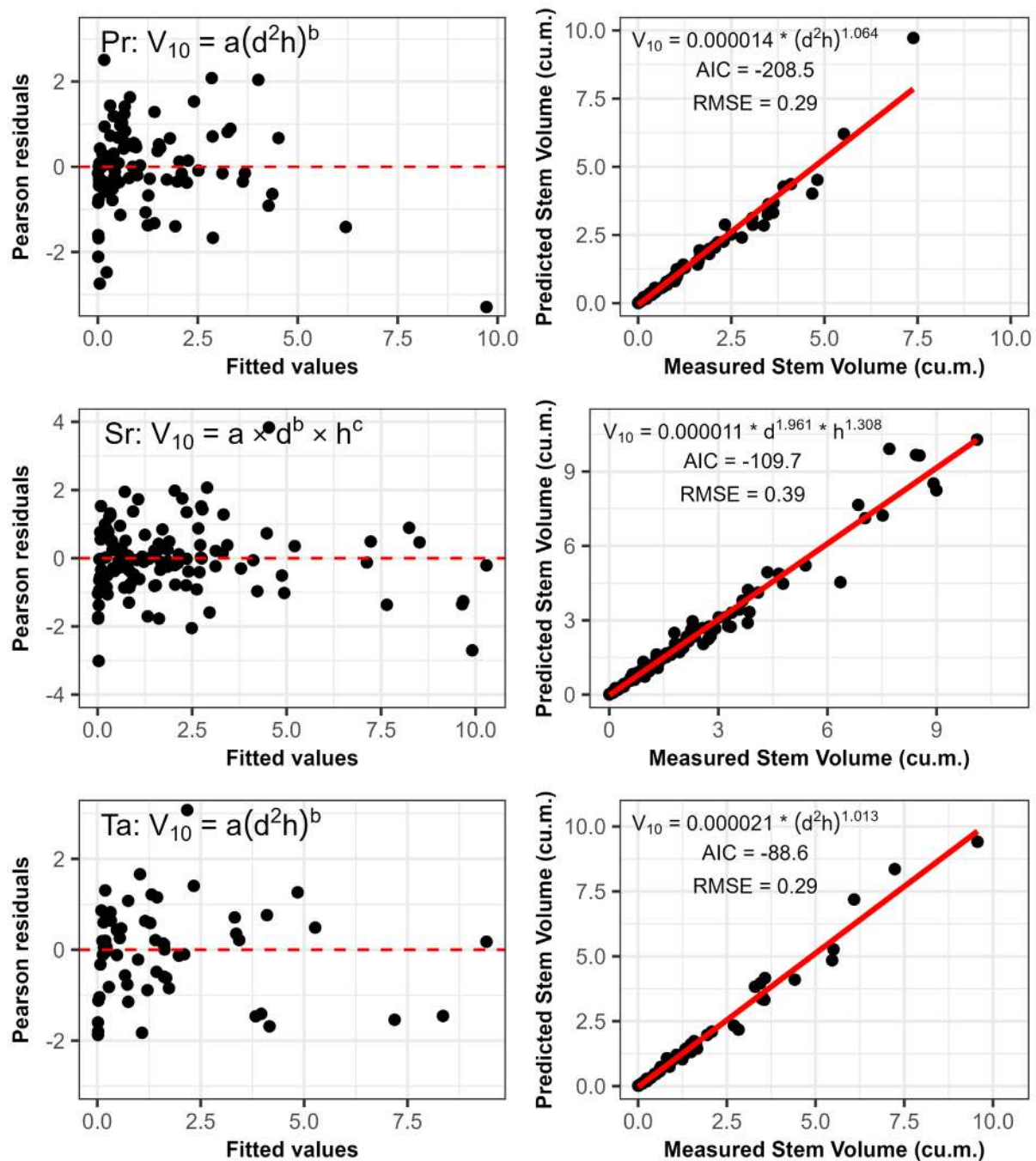


Figure 9: Graphical presentation of residuals of selected models for stem volume up to 10cm top diameter of all seven species (a) Residual distribution along the fitted values of selected models and (b) Observed vs predicted volume (cu. m.). For tree code (An, Cs, Lp, Sw, Pr, Sr, Ta) refer Table 1.

3.2 Allometric Equations for Biomass

3.2.1 Total Biomass

Among five candidate models tested for total biomass two models were found the best-fitted across all the seven tree species. The model 10 (M10: $B = a * (d^2hp)^b + e$) was best fit for five species (*Shorea robusta*, *Schima wallichii*, *Lagerstroemia parviflora*, *Terminalia alata*, and *Alnus nepalensis*), while the model

9 (M9: $B = a * d^b * h^c + e$) performed best for *Castanopsis* spp. and *Pinus roxburghii*. The inclusion of tree density as a predictor variable enhanced model performance for above-mentioned five species among the candidate models (Annex VI). But inclusion of density in predictor variable could not improve the model performance for *Castanopsis* spp. and *P. roxburghii* (Table 9 and figure 10) therefore, we dropped the density in the suggested equations

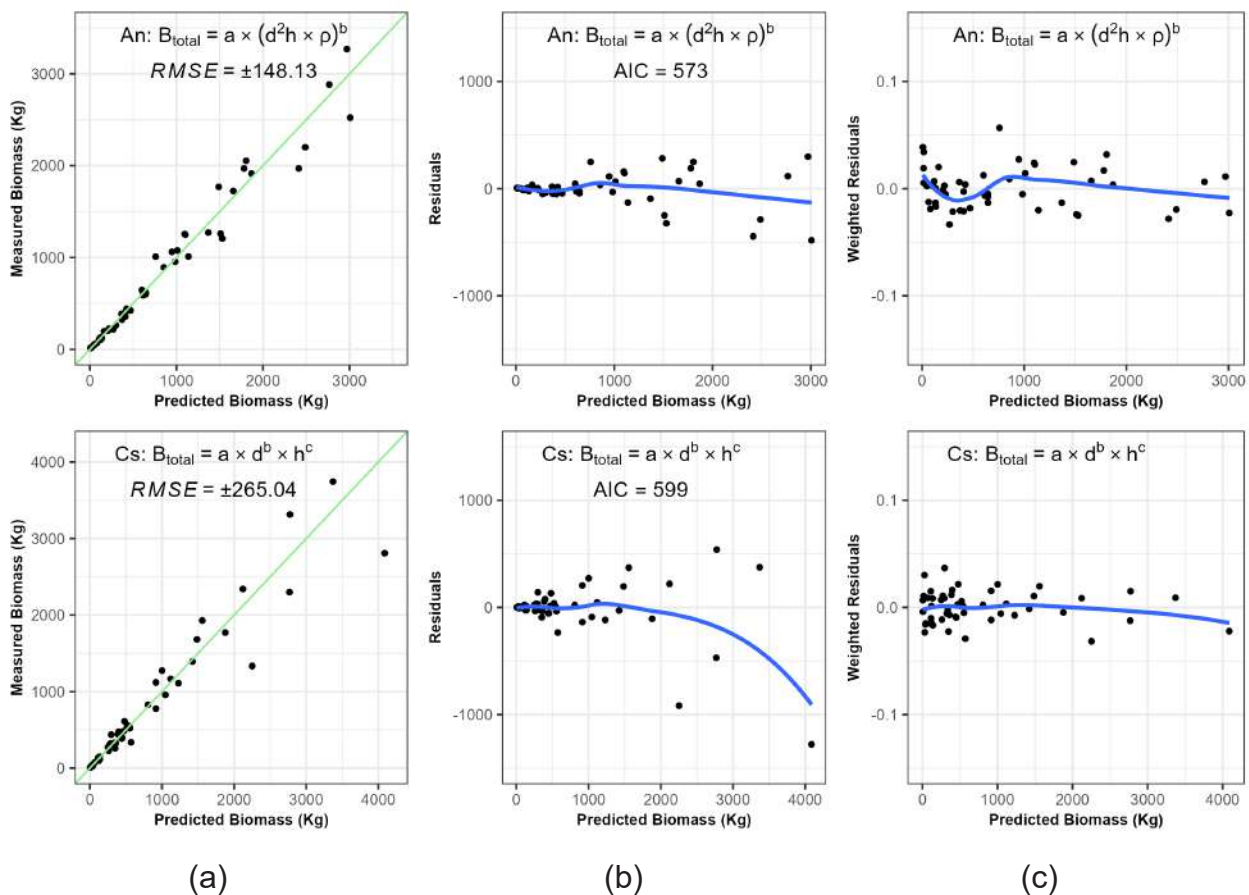
Table 9 : Summary statistics of best fitted model for total biomass of all seven species.

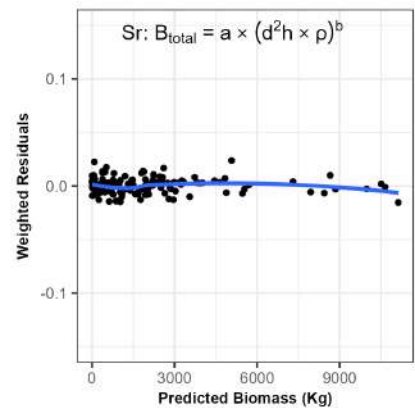
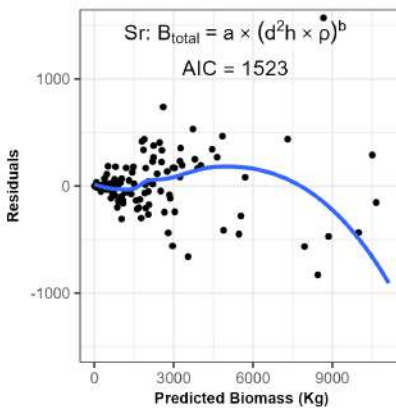
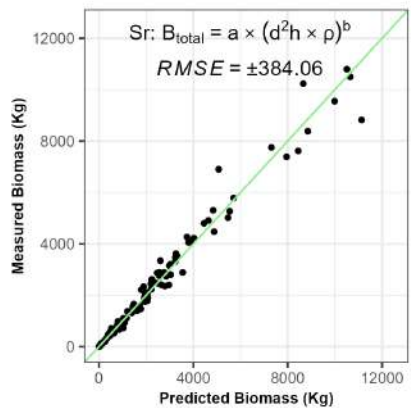
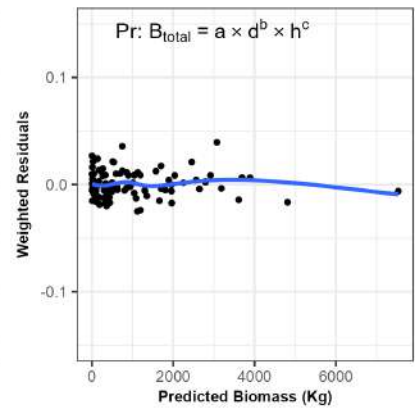
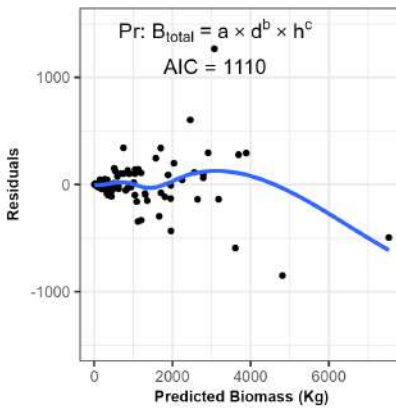
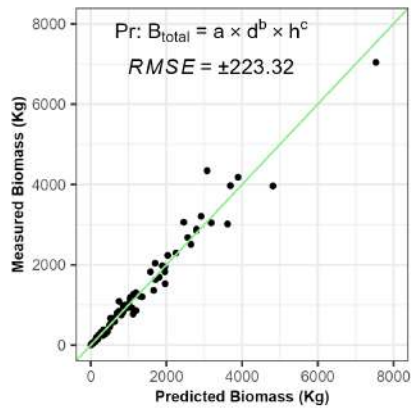
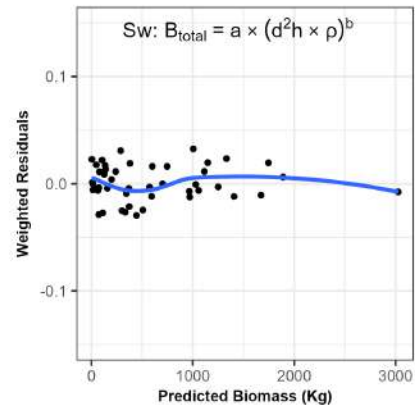
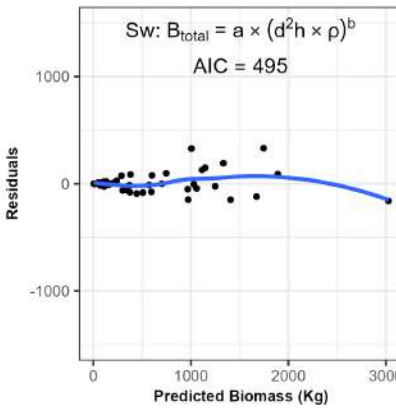
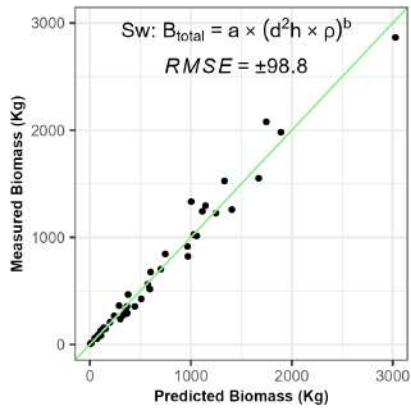
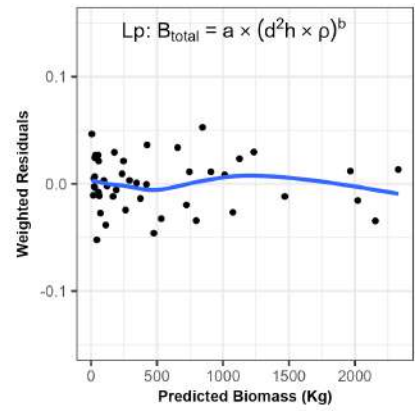
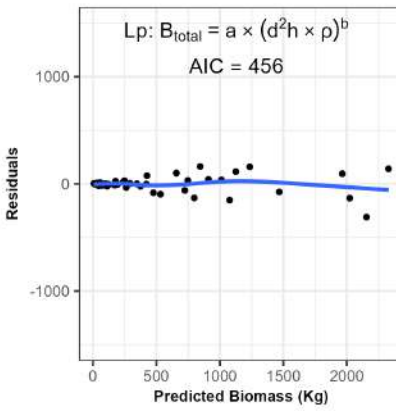
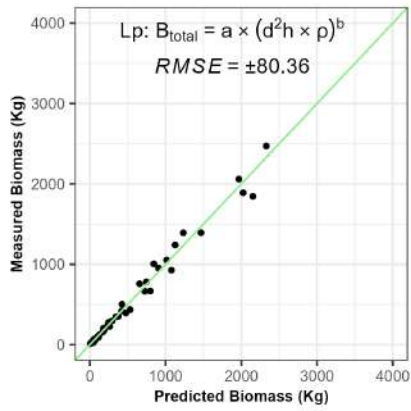
Biomass portion	Equation	n	a	b	c	AIC	RMSE	MB	Adj R ²
<i>Alnus nepalensis</i>	$B = a * (d^2hp)^b$	52	0.067139	0.956808	-	572.91	148.1	-6.34	0.97
<i>Castanopsis</i> spp.	$B = a * d^b * h^c$	52	0.071253	2.318525	0.299393	599.48	265.0	-18.14	0.90
<i>Lagerstroemia parviflora</i>	$B = a * (d^2hp)^b$	46	0.060964	0.971369	-	455.63	80.4	-2.10	0.98
<i>Pinus roxburghii</i>	$B = a * d^b * h^c$	96	0.031693	2.329281	0.519366	1110.16	223.3	2.84	0.97
<i>Shorea robusta</i>	$B = a * (d^2hp)^b$	122	0.054968	0.980885	-	1522.86	384.1	13.57	0.97
<i>Schima wallichii</i>	$B = a * (d^2hp)^b$	47	0.071359	0.951091	-	494.61	98.8	9.56	0.98
<i>Terminalia alata</i>	$B = a * (d^2hp)^b$	61	0.080156	0.943341	-	736.85	433.2	-71.49	0.95

Note: All the parameter were significant at 0.05% significance level.

for these two species. *L. parviflora*, *A. nepalensis* and *Castanopsis* spp. have a little bit negative bias with small RMSE but the *P. roxburghii*, *S. robusta* and *S. wallichii* have little bit positive bias with moderate RMSE. But *T. alata* has a comparatively larger negative bias (Table 9). The larger RMSE of *Shorea* and *Terminalia* might be due to larger variation in tree size and structure of the species. The detailed statistics and residuals of candidate models were given in Annex VI.

The Figure 10 shows all the models have homoscedasticity of residuals after the weight in the equation. The residuals were randomly scattered around the zero line of residuals. Moreover, the residuals were distributed above and below the predicted versus measured fitted lines almost equally (Figure 10). The residuals of all tested models were given in Annex VI.





(a)

(b)

(c)

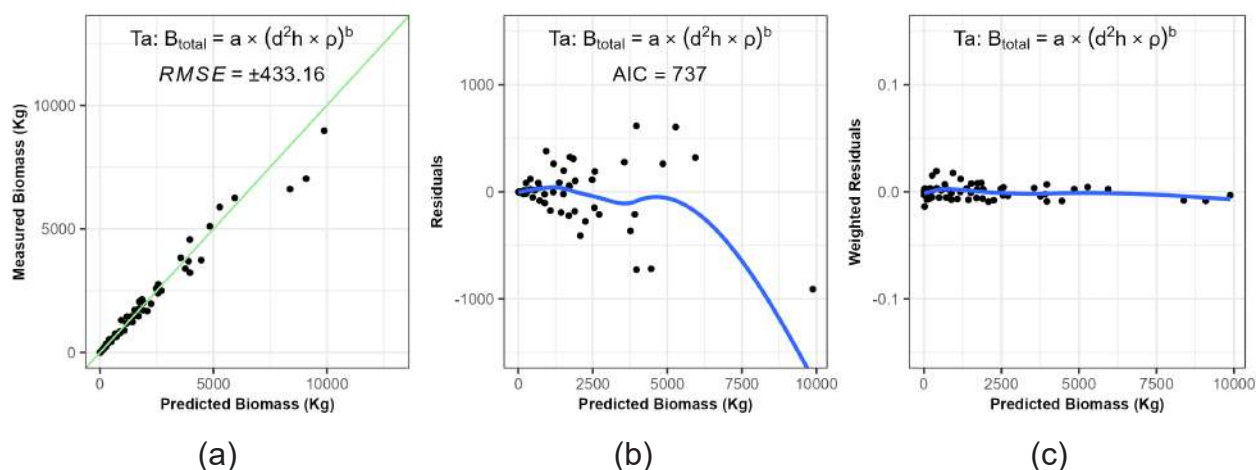


Figure 10: Graphical presentation of residuals of selected total biomass models (a) shows the comparison between predicted and actual stem biomass (kg), (b) displays the residuals against the predicted biomass, (c) shows the weighted residuals against the predicted biomass. For tree code (An, Cs, Lp, Sw, Pr, Sr, Ta) refer Table 1.

3.2.2 Stem Biomass

Species-specific allometric equations were developed to estimate stem biomass using combinations of diameter, height, and wood density. Model performance was evaluated using the AIC, RMSE, Mean Bias (MB) and residual analysis among the tested models of all species (Annex VII). Primarily we choose the models of lowest AIC considering the RMSE, MB and residuals among the all tested models within the species. As in total biomass models, *Schima wallichii* performed the best models without density ($B = a * d^b * h^c$) and all other models performed the best models using the density with height and diameter ($B = a * (d^2hp)^b$). RMSE values ranged from 45.5 kg (*S. wallichii*) to 273.5 kg (*S. robusta*), indicating considerable variation in prediction accuracy across species. Lower RMSE values in *S. wallichii* (45.5 kg), *L. parviflora* (61.6 kg), and *Castanopsis* spp

(109.7 kg) demonstrate high predictive accuracy. Higher RMSE values for *T. alata* (186.8 kg), *A. nepalensis* (118.6 kg), and particularly *S. robusta* (273.5 kg) indicate greater deviations between observed and predicted biomass, likely due to larger size ranges and structural variability within these two tropical species. Mean Bias (MB) values were generally low for most species, indicating minimal systematic over or underestimation. *S. wallichii* (MB = -0.29) and *P. roxburghii* (MB = -2.09) showed almost negligible bias, reflecting highly balanced predictions. Slight positive biases were observed in *L. parviflora* (MB = 3.30) and *S. robusta* (MB = 10.62), suggesting marginal overestimation of biomass. Negative biases in *A. nepalensis* (MB = -26.46), *T. alata* (MB = -12.43), and *Castanopsis* spp. (MB = -9.79) indicate a tendency toward underestimation, with moderate magnitude (Table 10).

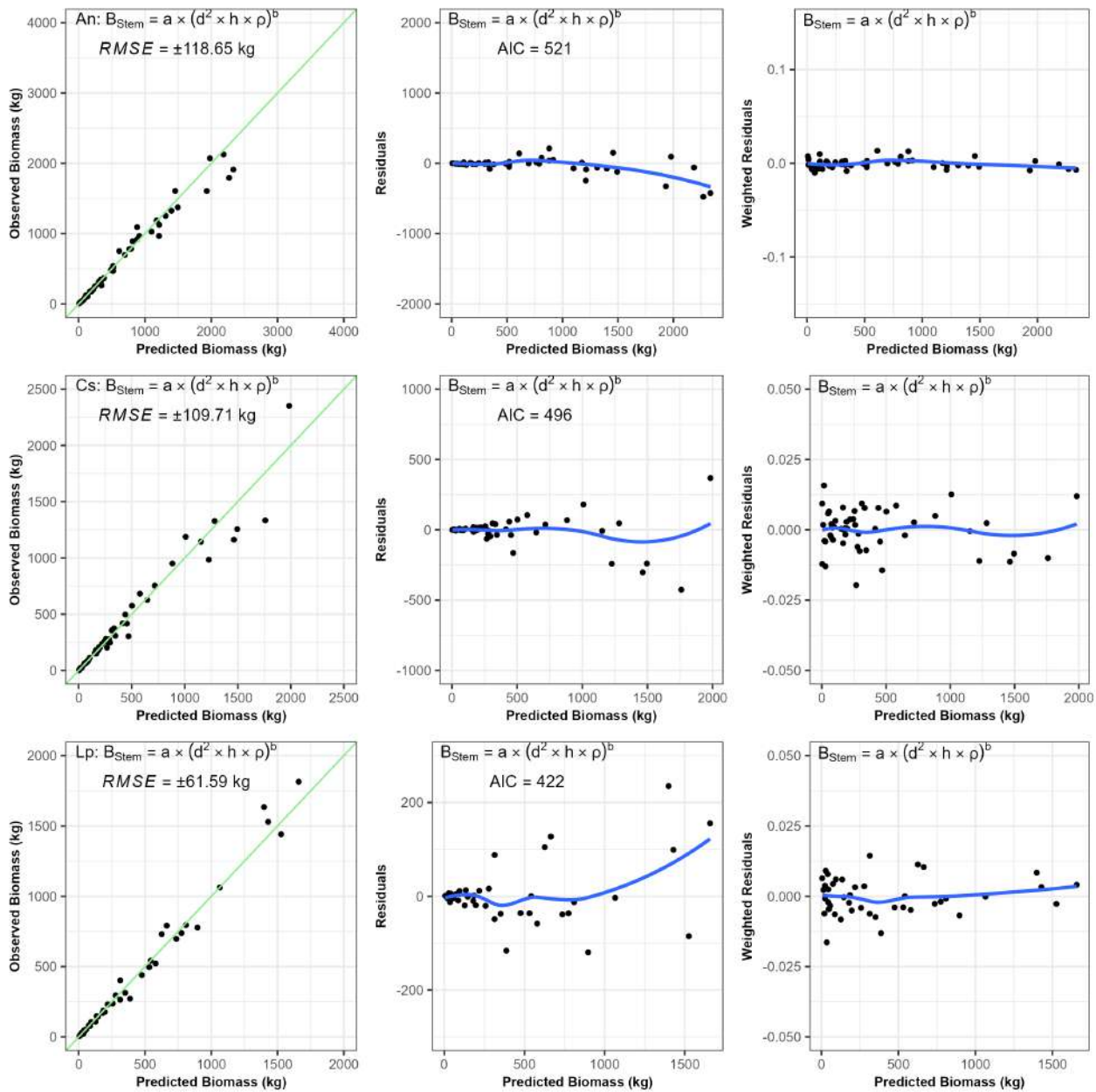
Table 10: Summary statistics of best fitted stem biomass models of all seven species

Stem biomass	Equation	n	a	b	c	AIC	RMSE	MB	Adj R ²
<i>Alnus nepalensis</i>	$B = a * (d^2hp)^b$	52	0.060094	0.946166	-	521.15	118.6	-26.46	0.95
<i>Castanopsis</i> spp.	$B = a * (d^2hp)^b$	52	0.062227	0.933040	-	495.57	109.7	-9.79	0.95
<i>Lagerstroemia parviflora</i>	$B = a * (d^2hp)^b$	46	0.059210	0.941559	-	421.57	61.6	3.30	0.98
<i>Pinus roxburghii</i>	$B = a * (d^2hp)^b$	96	0.054893	0.960175	-	952.22	136.7	-2.09	0.98
<i>Shorea robusta</i>	$B = a * (d^2hp)^b$	122	0.056689	0.949760	-	1436.34	273.5	10.62	0.98
<i>Schima wallichii</i>	$B = a * d^b * h^c$	47	0.017416	1.793677	1.210074	448.73	45.5	-0.29	0.99
<i>Terminalia alata</i>	$B = a * (d^2hp)^b$	61	0.064566	0.934114	-	659.71	186.8	-12.43	0.99

Note: All the parameter were significant at 0.05% significance level.

The residuals without weight show the larger variance then the equation was weighted. After the weighted, residuals show almost equal variance throughout the predicted biomass range. All the residuals were randomly distributed around the 0 line of residuals distribution however some residuals scattered a little far from the centre. For example in Sw some point

went in lower side but the range was within 0.05. However, in overall equations, residuals was not skewed more than the total biomass models. In spite of this the predicted vs. observed graph shows the models are good predictability (Figure 11). The detailed residuals of all tested models were given in Annex VII.



(a)

(b)

(c)

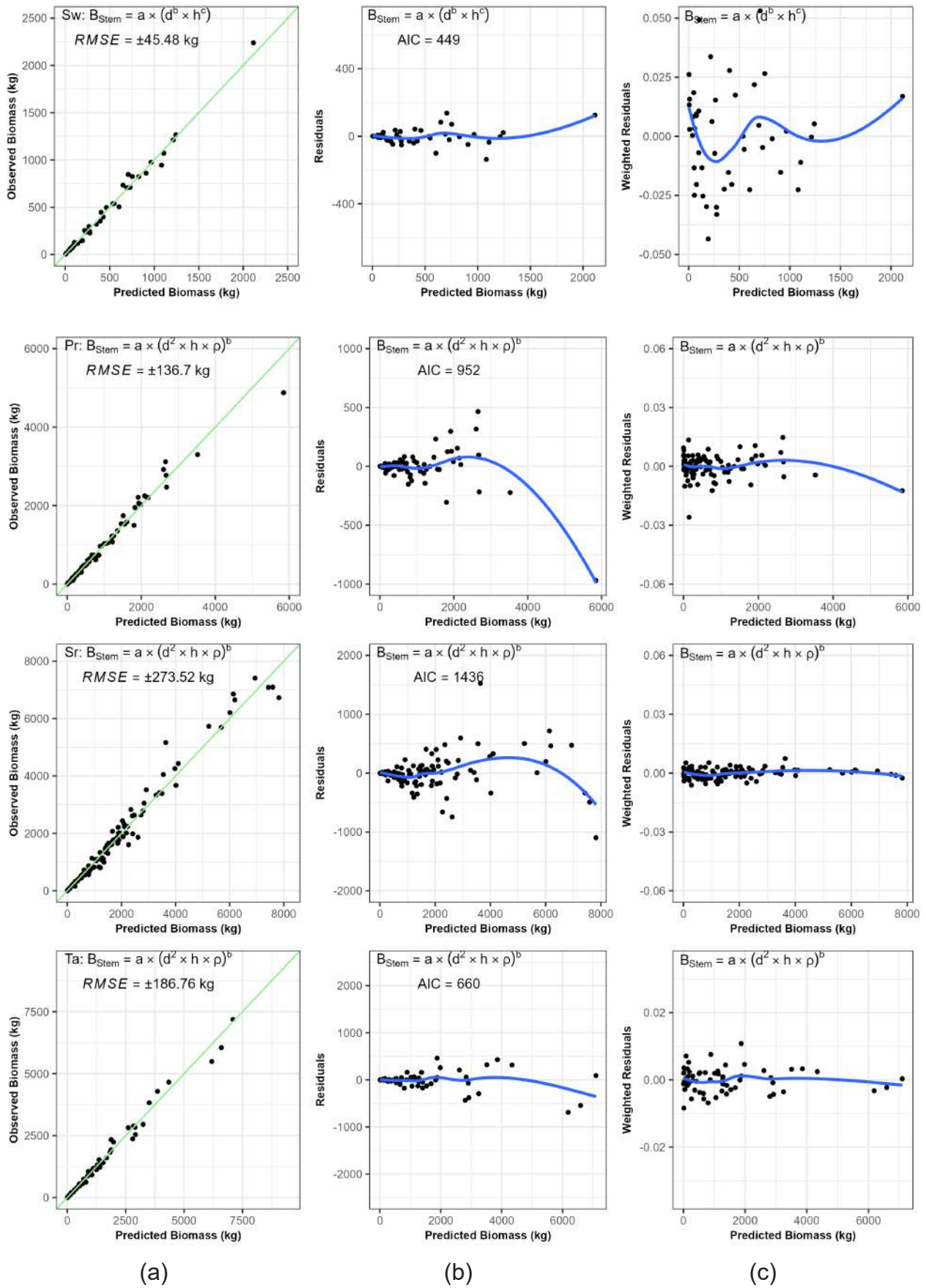


Figure 11 : Graphical presentation of residuals of selected stem biomass models of all seven species, (a) shows the comparison between predicted and actual biomass (kg), (b) the residuals against the predicted biomass, (c) the weighted residuals against the predicted biomass where is (a), (b) & (c). For tree code (An, Cs, Lp, Sw, Pr, Sr, Ta) refer Table 1.

3.3 Testing Biomass Models Using Species Average Density

The best performance model was found when the Individual tree density was used as an important predictor variable for total biomass models except *Castanopsis* and *Pinus*. Similarly for stem biomass except *Schima* all other species performed best result combined with density as predictor variable for stem biomass. However,

the user may not have the density value of each tree, for this purpose, the density of each species was derived from observed stem biomass, and then compared with biomass values predicted by the models. We evaluated the performance, using the paired *t* test of the suggested models, whether differences between observed and predicted biomass were statistically significant or not and calculated RMSE to know the losing performance of the models. The comparison

Table 11 : Recommended density for total and stem biomass models. Comparing biomass predictions models using individual tree density and species average tree density. Then again comparing the biomass predictions models using individual tree density and diameter classwise tree density in case of significant difference. The p values from the paired t-test at 95% confidence level and evaluating model performance using Root Mean Square Error (RMSE). Species that do not include density in their model indicated as NA. (1, 2, 3, 4 represents 5 -10 cm>10-30 cm>30 - 50 cm and >50 cm DBH tree class respectively)

Biomass portion	Species	RMSE using individual tree density (kg)	RMSE using spp. average density (kg)	P-value *	RMSE using dia-class tree density (kg)	P-value **	Recommended density (gm/cm ³)
Stem Biomass	An	118.6	157.74	0.419	-	-	0.4287
	Cs	109.7	107.44	0.1612	-	-	0.4936
	Lp	61.6	72.79	0.70	-	-	0.5684
	Pr	136.7	161.19	0.0058	136.2	0.3735	1 = 0.3950
							2 = 0.4283
							3 = 0.4658
							4 = 0.5225
	Sr	273.52	296.13	<0.001	257.85	0.3942	1 = 0.5042
							2 = 0.5574
							3 = 0.6384
							4 = 0.6628
	Sw	NA	NA	NA	-	-	-
Ta	186.76	221.54	0.0298	216.53	0.9952	1 = 0.4865	
						2 = 0.5801	
						3 = 0.6562	
						4 = 0.6880	
Total Biomass	An	148.13	184.897	0.39	-	-	0.4318
	Cs	NA	NA	NA	-	-	-
	Lp	80.364	92.431	0.725	-	-	0.5651
	Pr	NA	NA	NA	-	-	-
	Sr	384.061	386.592	< 0.001	354.007	0.2342	1 = 0.5042
							2 = 0.5573
							3 = 0.6331
							4 = 0.6551
	Sw	98.797	117.852	0.061	-	-	0.4869
	Ta	433.167	351.852	0.041	412.501	0.8876	1 = 0.4865
2 = 0.5780							
3 = 0.6472							
4 = 0.6819							

Note: P value * = comparing predicted biomass through using individual tree density and species average density
P value ** = comparing predicted biomass through using individual tree density and diameter class wise density.
Tree species code is described in Table 1.

was summarized in Table 11, which presents the root mean square error (RMSE) of biomass predictions when using species average density and individual tree density.

We found that there was no significant difference for *L. parviflora*, and *A. nepalensis* but *S. robusta* and *T. alata* were found significant difference for both total and stem biomass. *S. wallichii* was also found significant for only total biomass. In addition *Castanopsis* spp. was also found insignificant and *P. roxburghii* was found significant for stem biomass. Then we used a segmented regression test at 95% confidence level for all significant species and further classified the density on three different diameter classes and used these densities for trees of corresponding diameter and species. After that, we found no significant difference (Table 11). Thus we recommend using the diameter class wise density for these species and species average density for all other species.

This analysis highlights the trade off between practicality and accuracy: while species average density simplifies data collection, it may reduce predictive precision for certain species. This information helps in evaluating the implications of using average versus individual tree density in biomass modeling. In general, RMSE values increased when species average density was used, except in the case of Total biomass of *T. alata*, where the model performance remained stable.

3.4 Model Validation

The total stem volume predicted by the historical volume model of Sharma & Pukkala (1990) and the recommended model of this study was overlaid on an independent data set of *Alnus nepalensis* collected from the Kavrepalanchok and Sindhupalchok districts by FRTC Godawari, as well as on an independent data set of *S. robusta* from the Banke district reported by Subedi (2021) (Figure 12). The comparison shows that the predicted volume of *A. nepalensis* does not differ noticeably up to 40 cm DBH; above this point, the distinction becomes clearer, although both models still appear to overestimate the volume. We can expect that if there were more trees of higher diameter it would be more distinct the total stem volume prediction between these two equations. In contrast, the predicted volume of *S. robusta* differs slightly across the entire diameter range (Figure 12). The paired t-test indicated significant differences for both species between their respective predicted volumes (*A. nepalensis*: $df = 87$, $p = 6.129 \times 10^{-5}$; *S. robusta*: $df = 46$, $p = 4.458 \times 10^{-10}$). The RMSE values of *A. nepalensis* was found 0.328 and 0.302 which was 7.93 % improvement. Similarly, the improvement of RMSE for *S. robusta* was 6.36% than the total stem volume prediction of Sharma & Pukkala 1990. Thus, these recommended models were more robust and had better prediction capacity.

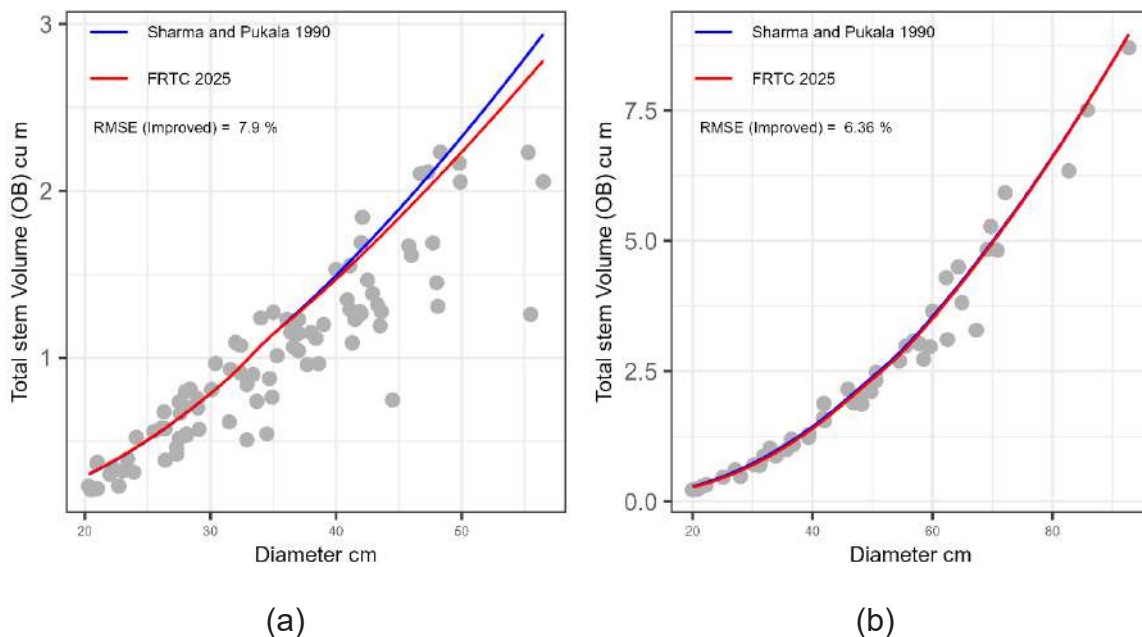


Figure 12 : Models validation through independent datasets. Two models of Sharma & Pukkla, 1990 and FRTC 2025 was overlaid to the independent datasets of (a) *A. nepalensis* and (b) *S. robusta*

All the models were validated by leave one out cross validation. The RMSE of model development and validation was found similar, however the prediction error in some cases jumped a bit far than 90 or 10 percentile. This often happens in biomass models because some trees weigh far more or far less than others of similar dimensions in nature, especially very large ones. This shows the model would be good for estimating average biomass across plots or populations. However, it may be less reliable for estimating the biomass of individual trees. All the RMSE difference between model development and validation was found to be less

than 5 percent. The RMSE difference percent in up to top 20 cm diameter volume models are a little bit higher though the prediction error is less (Table 13). The higher difference in volume up to top 20 cm diameter was mainly due to the very small value. The maximum and minimum values indicate there were still some outliers or large-tree scaling issues, which is common in biomass models.

In general there is not very large difference in model RMSE and validation RMSE this shows the model is not overfitting and can be generalized reasonably well.

Table 12: The comparison of suggested models through the RMSE of leave one out cross validation

SN	Species Code	Variable	Recommended Models	Model RMSE	LOOCV RMSE	Prediction error (LOOCV)			
						Min	P10	P90	Max
1	An	Total Stem Volume	$V = a * db * hc$	0.19	0.2089	-0.5375	-0.1388	0.1378	0.8912
2	Cs	Total Stem Volume	$V = a * (d^2h)b$	0.222	0.2339	-0.7189	-0.1091	0.1176	0.9565
3	Lp	Total Stem Volume	$V = a * (d^2h)b$	0.11	0.1175	-0.4692	-0.1623	0.0802	0.2300
4	Pr	Total Stem Volume	$V = a * (d^2h)b$	0.25	0.2631	-0.8475	-0.1618	0.1420	1.8419
5	Sr	Total Stem Volume	$V = a * (d^2h)b$	0.41	0.4195	-2.2987	-0.4003	0.3277	1.6017
6	Sw	Total Stem Volume	$V = a * db * hc$	0.08	0.0933	-0.2506	-0.1020	0.0956	0.3324
7	Ta	Total Stem Volume	$V = a * (d^2h)b$	0.27	0.2767	-0.7088	-0.2747	0.2589	0.9138
8	An	Volume Top 10 cm	$V = a * db * hc$	0.19	0.1841	-0.4266	-0.0657	0.1577	0.8089
9	Cs	Volume Top 10 cm	$V = a * (d^2h)b$	0.21	0.2108	-0.5711	-0.1535	0.1472	0.7492
10	Lp	Volume Top 10 cm	$V = a * (d^2h)b$	0.09	0.0932	-0.2144	-0.0786	0.0811	0.3311
11	Pr	Volume Top 10 cm	$V = a * (d^2h)b$	0.29	0.2913	-0.6626	-0.1111	0.1377	2.3259
12	Sr	Volume Top 10 cm	$V = a * db * hc$	0.39	0.3852	-1.8252	-0.2673	0.2151	2.2072
13	Sw	Volume Top 10 cm	$V = a * db * hc$	0.06	0.0604	-0.1237	-0.0851	0.0571	0.1799
14	Ta	Volume Top 10 cm	$V = a * (d^2h)b$	0.29	0.2891	-0.6664	-0.2245	0.1703	1.1212
15	An	Volume Top 20 cm	$V = a * (d^2h)b$	0.28	0.3241	-0.6536	-0.3980	0.1432	1.0447
16	Cs	Volume Top 20 cm	$V = a * (d^2h)b$	0.23	0.2731	-0.8687	-0.2930	0.1462	0.8247
17	Lp	Volume Top 20 cm	$V = a + b (d^2h)$	0.11	0.1585	-0.3364	-0.2563	0.0243	0.2773
18	Pr	Volume Top 20 cm	$V = a * (d^2h)b$	0.35	0.4079	-0.8007	-0.2638	0.0739	3.1493
19	Sr	Volume Top 20 cm	$V = a * (d^2h)b$	0.46	0.4867	-1.9105	-0.3779	0.3390	2.6178
20	Sw	Volume Top 20 cm	$V = a * db * hc$	0.07	0.1018	-0.1941	-0.1721	-0.0100	0.1636

SN	Species Code	Variable	Recommended Models	Model RMSE	LOOCV RMSE	Prediction error (LOOCV)			
						Min	P10	P90	Max
21	Ta	Volume Top 20 cm	$V = a * (d^2h)b$	0.34	0.3759	-0.8213	-0.3482	0.2137	1.5197
22	An	Total Biomass	$B = a * (d^2hp)b$	148.1	155.5309	-309.9144	-162.6385	131.2962	512.6763
23	Cs	Total Biomass	$B = a * db * hc$	265	283.4852	-570.7583	-225.6228	121.3697	1382.8293
24	Lp	Total Biomass	$B = a *(d^2hp)b$	80.4	86.5418	-171.5495	-105.3863	91.7927	344.8671
25	Pr	Total Biomass	$B = a * db * hc$	223.3	231.5000	-1312.6330	-149.4431	141.9081	898.8038
26	Sr	Total Biomass	$B = a *(d^2hp)b$	384.1	392.8424	-1857.7387	-342.2569	282.3764	2405.7210
27	Sw	Total Biomass	$B = a *(d^2hp)b$	98.8	102.7956	-344.6667	-113.9399	88.4422	176.2089
28	Ta	Total Biomass	$B = a *(d^2hp)b$	433.2	446.2722	-634.2398	-283.4179	375.5195	2113.1889
29	An	Stem Biomass	$B = a * (d^2hp)b$	129.1	132.9848	-218.4756	-50.5622	96.9080	572.0533
30	Cs	Stem Biomass	$B = a *(d^2hp)b$	107.5	113.2776	-397.5878	-58.4471	66.0951	423.1014
31	Lp	Stem Biomass	$B = a *(d^2hp)b$	63	66.5946	-254.6180	-95.3081	45.4648	123.6846
32	Pr	Stem Biomass	$B = a *(d^2hp)b$	135.5	143.9993	-534.4444	-76.1505	68.7197	990.0573
33	Sr	Stem Biomass	$B = a *(d^2hp)b$	267.5	270.9926	-1500.7433	-303.2703	211.0065	1191.8649
34	Sw	Stem Biomass	$B = a * db * hc$	45.5	49.8192	-149.0056	-40.1012	46.5309	151.2118
35	Ta	Stem Biomass	$B = a *(d^2hp)b$	181.1	186.5555	-464.1212	-176.8184	175.0321	652.9376

3.5 Average Wood Density

The study found the wood density of the seven tree species varied between 428 and 628 kg/m³, with *Alnus nepalensis* being the least dense and *Terminalia alata* species the densest. The bark density was lesser than the wood density (Table 13 and Table 14). Similarly the branch density was found less than stem density (Table 13 and Table 14).

Although air dry density is not constant and generally not used for comparison, we calculate the air dry density and given in Table 13 and Table 14.



Average Density Stem and Large branch with Bark

Table 13: Average density of stem

Species	No. of Observations	Stem with bark						Stem without bark					
		Air Dry Density (kg/m ³)			Oven Dry Density (kg/m ³)			Air Dry Density (kg/m ³)			Oven Dry Density (kg/m ³)		
		Mean	Range (Min/Max)	SD	Mean	Range (Min/Max)	SD	Mean	Range (Min/Max)	SD	Mean	Range (Min/Max)	SD
<i>Alnus nepalensis</i>	52	471.9	434.5/524.3	34.1	428.7	394.1/454.0	22.9	499.2	443.8/577.0	37.9	424.0	382.0/462.0	29.4
<i>Castanopsis spp.</i>	52	552.7	500.4/616.1	41.0	493.6	456.1/530.0	23.1	597.0	563.2/649.1	30.9	514.4	484.2/552.2	21.3
<i>Lagerstromia parviflora</i>	50	596.1	528.1/688.4	53.4	568.4	481.6/659.1	56.0	706.2	667.3/767.1	37.3	611.7	549.8/693.4	43.5
<i>Pinus roxburghii</i>	97	543.8	437.4/685.8	71.8	478.5	395.0/568.8	58.8	576.9	505.9/711.6	66.2	508.7	431.5/594.0	55.3
<i>Shorea robusta</i>	124	703.7	602.5/771.4	61.7	631.5	504.2/687.0	61.1	774.7	664.1/885.7	68.7	675.4	575.5/715.4	46.9
<i>Schima wallichii</i>	49	540.8	458.0/622.7	61.8	487.2	427.1/528.0	34.8	651.0	595.6/685.7	34.3	557.0	529.5/584.1	18.3
<i>Terminalia alata</i>	64	728.9	672.6/778.7	39.3	653.1	486.5/751.4	73.6	777.7	634.2/898.5	75.9	694.2	564.6/766.2	54.7

Table 14: Average density of stem and branches

Species	No. of Observations	Stem and big branches with bark						Stem and big branches without bark					
		Air Dry Density (kg/m ³)			Oven Dry Density (kg/m ³)			Air Dry Density (kg/m ³)			Oven Dry Density (kg/m ³)		
		Mean	Range (Min/Max)	SD	Mean	Range (Min/Max)	SD	Mean	Range (Min/Max)	SD	Mean	Range (Min/Max)	SD
<i>Alnus nepalensis</i>	52	487.4	450.1/525.7	25.7	431.8	397.7/457.3	20.5	500.3	444.1/577.0	37.2	428.0	390.5/464.3	26.1
<i>Castanopsis spp.</i>	52	539.3	478.6/574.2	29.9	489.6	456.1/520.5	20.4	582.7	567.2/601.4	14.1	513.6	484.2/550.4	20.7
<i>Lagerstromia parviflora</i>	50	635.4	569.2/695.3	36.8	565.1	481.6/653.2	53.3	695.6	667.3/670.0	32.6	614.5	549.8/695.1	44.6
<i>Pinus roxburghii</i>	97	529.7	461.8/609.8	50.6	476.3	395.0/559.0	56.4	566.4	505.9/635.3	53.3	503.3	431.5/583.0	55.2
<i>Shorea robusta</i>	124	682.5	565.6/753.0	50.7	626.8	504.2/680.5	58.6	744.1	644.1/810.1	45.9	675.7	575.5/714.5	47.5
<i>Schima wallichii</i>	49	537.0	489.1/572.7	31.9	486.9	427.1/527.5	35.0	631.2	595.6/664.5	28.2	557.9	529.5/584.7	18.9
<i>Terminalia alata</i>	64	679.4	522.6/764.7	70.9	647.7	486.5/732.9	70.3	738.7	634.2/795.8	49.7	724.9	564.6/965.2	109.2

Note: Branches >10 cm over bark diameter



4. Discussion

The primary objective of any national level volume or biomass equations should be proper prediction of the total amount of biomass and volume of the nation through applying the national forest inventories. Therefore, samples should be selected as unbiased and proper representation of the population. However, due to the destructive nature of collecting primary data to prepare allometric equations, most of the researchers prepare equations from available samples (convenience sampling) or non-destructively measured samples (Sharma & Pukkala, 1990) or from the limited area (Subedi *et al.*, 2021, Sheikh *et al.*, 2011) and limited number of destructive samples of specific species (Sheikh *et al.*, 2011). As in many destructive studies, this study has also limited the number of samples. But this study applied a rigorous and nationally representative sampling design that ensured adequate coverage across ecological gradients, diameter classes, and physiographic zones of Nepal. The stratified random selection of sample trees, coupled with destructive sampling and standardized field protocols, minimized sampling and measurement bias which strengthened the reliability of the derived models.

By adopting dual-phase drying (air and oven) and employing quality assurance checks across laboratories, the study maintained high analytical precision in density and biomass estimation. Compared to earlier works such as Sharma & Pukkala (1990), this design represents a major methodological advancement, particularly through representative sampling, improved measurement accuracy, clearer and transparent documentation, first hand density and biomass data and more balanced sample sizes.

Newton's, Smalian's or Huber's formula have long been applied in forestry research for calculating log volume. Among these, Newton's formula is generally regarded as the most accurate. However, when logs are subdivided into short sections, the systematic bias inherent in these cross-sectional formulas is reduced, leading to estimates that more closely approximate those all three formulas since the diameter difference between two ends decreases. For this reason, comparisons among the classical

formulas are typically based on sections of similar length. Several studies have shown that Smalian's formula can provide estimates equivalent to, or in some cases more accurate than, Newton's formula (Durkaya & Durkaya, 2011; Sahin & Komak, 2022) when Smalian's formula considered half length of two logs but Newton's formula considered long one log. Ozcelik (2008), for example, treated Smalian's estimate for 1-m sections as a reference "true volume," a practice echoed in other studies (e.g., Lisboa *et al.*, 2018; Laamanen *et al.*, 1995). The widespread use of Smalian's formula is partly attributable to its operational simplicity, both in the field and data processing. In this study, Smalian's formula was therefore selected for calculating the volume of all sectional logs, even though the measurements necessary for applying Newton's formula were also collected. Tree volume and biomass were computed above stump height (0.3 m), with the stump considered non-merchantable because it does not contribute to timber yield. This treatment is consistent with previous work, including Sharma & Pukkala (1990). If the biomass or volume of trees from ground level to tip of the tree is needed, the volume or biomass of the stump should be added which is given in Annex II.

In almost all of the empirical relationships for biomass or volume, the explanatory variables were always the DBH and total tree height or a combination of these two variables. Moreover, equations with several other independent variables have been also widely developed but the selection of variables is highly dependent on local conditions and intended use of equations (Zianis *et al.*, 2004). Realising these facts, this report included only total height and DBH however there will be few technical publication in 2026, incorporating all the variables collected in the field, specially for the contribution to the science. Total stem volume is mostly needed for planning forest inventories but in management level merchantable volume without bark up to specified ober-bark diameter is needed. Thus in this study, we prepared these three equations for volume and two biomass equations. Volume and biomass of the branches were given in ratio (Annex VIII) for more simplicity and the practicable point of view.

Non-linear models consistently outperformed linear forms in predicting both volume and biomass (Baral *et al.*, 2021), reflecting the non-proportional relationship between tree dimensions and mass or volume. Therefore, we did not include the transformed linear models in the candidate models. Among the candidate models, power functions of the form ($B_i, V_i = a * D^b * H^c, V_i = a * (d^2h)^b$ and $B = a * (d^2hp)^b$) provided the best fits, as indicated by the lowest AIC and RMSE values and well-distributed residuals.

These formulations align with previous findings that emphasize multiplicative, size-dependent relationships between diameter, height, and density (Chave *et al.*, 2005; Henry *et al.*, 2011). The validation of leave one out cross validation (LOOCV) shows the strong performance of these models across all seven species demonstrates their robustness and suitability for national application. Moreover, validation through the local data shows that the updated equations improved accuracy over the Sharma & Pukkala models, as evidenced by lower RMSE and better fit across the full diameter range. This improvement reflects both technological progress and enhanced sampling design despite the limited number of samples. In addition, it can also be applicable to local areas such as particular community forest or particular districts. However, it was recommended to test before use for local areas. For both volume and biomass prediction we show all the equations of significant parameters so that the users may apply other than suggested models as per the research objective, need of accuracy or availability of input variable.

The species-specific wood density values (400–700 kg m³) observed in this study are broadly consistent with prior estimates for tropical and subtropical forests in the Himalayas (Sheikh *et al.*, 2011). Earlier study reported a basic wood density of *Alnus nepalensis* 0.319 g cm³, air-dry density of 0.376 and green density 0.601 g cm³ (Lamichhaney, 1995 referring to Limaya and Sen, 1956). This study shows the basic wood density of *A. nepalensis* is 0.427 g/cm³ and Sharma & Pukkala 1990, indicate the air dry density 390 kg/m³. This was a slightly higher than the previous study. However, the moisture content associated with the air-dry density measurement was not specified. Although air-dry density is commonly assumed to reflect a

moisture content of approximately 10–12%, this value is not constant and depends on ambient humidity and temperature at the time of measurement (Picard *et al.*, 2012). Similarly, Sharma & Pukkala (1990) reported the air dry density of *S. robusta* 880 kg/m³ and reported the biomass estimation was very inaccurate and imprecise for individual trees. In contrast, basic wood density, 0% moisture content defined as oven-dry mass divided by green volume at, is more reliable for comparison across studies and is widely recommended in international guidelines (IPCC, 2003). Laamanen *et al.*, (1995) reported the average basic wood density 0.682 kg/m³ and this study shows the average basic wood density 672.6 kg/m³ with the range of 476.9 to 883.1 kg/m³. This result is in line with previous studies of Laamanen *et al.*, (1995) though previously trees were measured only greater than 15 cm DBH and discs were dried only in 24 hours that might be causes of seen slightly higher side estimation. Moreover, this study clearly shows higher density for higher diameter trees. Similarly, the average basic wood density of *P. roxburghii* was reported 0.478 ranging from 0.308 to 0.652 (Ali *et al.*, 2020) and this study was found 0.548 g/cm³ which is in line with that study. Compared to regional studies in India, Bhutan, and Southeast Asia (e.g., Malimbwi *et al.*, 1994; Mugasha *et al.*, 2016), the predicted volumes and biomass values fall within similar ranges, confirming their biological plausibility and potential for cross-border applications under comparable ecological conditions.

During the validation meeting with forestry experts, some participants expressed concern that the density estimates obtained in this study appeared lower than previously reported values. This discrepancy may reflect methodological differences. For example, the water-displacement method often produces slightly lower density estimates than the geometric method, with reported ratios around 0.94 (Chave *et al.*, 2006). In addition, variation in wood density is known to occur across environmental gradients. Montane species typically exhibit lower wood density than lowland species (Chave *et al.*, 2006). Several studies have also documented contrasting relationships between wood density and site characteristics: Baker *et al.*, (2004) and Muller-Landau (2004) observed negative associations with soil fertility; Wiemann and Williamson (2002) reported a positive correlation with mean annual

precipitation; whereas Barajas-Morales (1987) found the opposite trend. Other studies, such as Steege and Hammond (2001), detected no significant association with precipitation or soil fertility. These inconsistencies underscore the species- and site-specific nature of wood density. Finally, it is important to note that volatile compounds are lost during drying above 100 °C, causing oven-dry carbon concentrations to underestimate true carbon content (Lamlom and Savidge, 2003).

The equations presented here substantially strengthen Nepal's capacity to report forest carbon stocks and changes with higher accuracy. The results support the transition from Tier 1 to Tier 2 or Tier 3 methodologies under IPCC guidelines, enhancing the credibility of the national GHG inventory and facilitating participation in REDD+ and other carbon financing mechanisms. The establishment of reliable wood density baselines and the air-dry to oven-dry conversion factors further contribute to standardizing biomass estimations across forest inventories and carbon monitoring frameworks. At the policy level, these models will enable evidence-based decision-making for forest management, restoration, and emission reduction initiatives.

The derived models are directly applicable to national forest inventories, carbon accounting, and biomass mapping at multiple spatial scales. They can also serve as reference tools of forest management for community forests, private plantations, and regional research.

Our review did not identify any published database that reports wood density for Nepalese tree species. Internationally, these equations can inform comparative studies in similar bioclimatic zones and contribute to global databases such as GlobAllomeTree¹. Their adoption will foster methodological harmonization and promote Nepal's leadership in transparent and science-based forest carbon monitoring.

Despite its comprehensive scope, some limitations remain. The scarcity of large-diameter

trees, especially for less common species and diameter classes, could not be included in samples even within the plan, constraining the ability to fully capture asymptotic growth patterns. Field activities were challenged by complex topography of Nepal and interspecific variation in silvicultural characteristics, particularly defoliation patterns and phenological timing. Furthermore, the medium-capacity oven used for drying samples prolonged laboratory processing, representing an additional operational constraint. Future model improvements should integrate larger samples of mature trees and incorporate environmental covariates (e.g., altitude, rainfall, soil properties) to account for ecological variability in tree allometry. Additionally, exploring mixed-effects modeling frameworks could further enhance predictive power by accommodating inter-site heterogeneity. The ongoing second phase covering additional nine species will complete the national allometric framework, ensuring over 75% coverage of Nepal's total stem volume.



¹ <https://www.globalloometree.org/>



5. Conclusions and Recommendations

This study provides the first nationally representative set of allometric equations for estimating tree volume and biomass in Nepal using rigorously sampled, destructively measured data. Diameter at breast height and total tree height emerged as the principal predictors of tree volume and biomass, and non-linear power functions consistently provided the most accurate and biologically realistic relationships. Power forms of models (M5 and M10) are found effective, outperforming previously available national models, particularly across broader diameter classes and ecological gradients.

The newly developed species-specific models substantially enhance Nepal's capacity to quantify forest carbon stocks with greater precision. Their application will support the country's progression from Tier 1 to higher-tier (Tier 2/3) methodologies under the IPCC framework, thereby improving the robustness of national GHG inventories, REDD+ reporting, and forest management planning. The density baselines and conversion factors generated here also establish essential reference values for

future biomass assessments, carbon accounting exercises, and forest resource inventories.

Despite their broad applicability, the models are constrained by limited representation of large-diameter individuals for some species and by operational challenges encountered during field and laboratory work. Further refinement should include increased sampling of mature trees and the incorporation of environmental covariates to better represent ecological variability. Mixed-effects modeling approaches may also strengthen predictive performance where site-level heterogeneity is substantial. The ongoing second phase, covering an additional nine species, is expected to extend national coverage to over 75% of the total stem volume, thereby completing the foundational framework for Nepal's allometric system. Although these models are well suited for national use, their application in small-scale settings such as community-managed or private forests should be approached as indicative rather than definitive, with local validation recommended whenever feasible. These steps will ensure that the allometric framework evolves into a comprehensive and reliable system for national carbon accounting and forest management.



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Annexes

Annex I

Description of the Species

S.N.	Local Name	English Name	Scientific Name	Family	Distribution Range (Min/Max Altitudes)	Native
1	Sal, Agrakh, Sakhuwa	Sal	<i>Shorea robusta</i> C.F. Gaertn.	Dipterocarpaceae	Tropical to Sub-tropical; (300/1,500 m)	Nepal , Bangladesh, East Himalaya, India, Tibet (China), West Himalaya
2	Asna, Saj	Indian laurel	<i>Terminalia alata</i> B. Heyne ex Roth	Combretaceae	Tropical to Sub-tropical (200/1,400m)	Nepal , India, Bangladesh, East Himalaya, West Himalaya
3	Botdhayaro, Botdhagero	Small Flowered Crape Myrtle	<i>Lagerstroemia parviflora</i> Roxb.	Lythraceae	Tropical to Sub-tropical (200/800 m)	Nepal , Bangladesh, India, Myanmar, East Himalaya, West Himalaya
4	Uttis	Alder	<i>Alnus nepalensis</i> D. Don	Betulaceae	Tropical to sub-tropical (primarily in wet tropical region) (500/2,600 m)	Nepal , Bangladesh, China (South and South-East), East Himalaya, Myanmar, Thailand, Vietnam, West Himalaya
5	Katus	Castanopsis	<i>Castanopsis</i> (D. Don) Spach species	Fagaceae	Tropical to Sub-tropical (450/2,900 m)	Nepal , Bangladesh, Tibet (China), South-East and South-Central), East Himalaya, Hainan, Laos, Myanmar, Taiwan, Thailand, Vietnam
6	Khote Sallo, Rani Sallo	Chir pine	<i>Pinus roxburghii</i> Sarg.	Pinaceae	Sub-tropical to Temperate (500/2,700 m)	Nepal , Bangladesh, East Himalaya, India, Pakistan, Tibet (China), West Himalaya
7	Chilaune	Needle wood tree, Schima tree	<i>Schima wallichii</i> (DC.) Korth.	Theaceae	Sub-tropical (rarely to Temperate) (900/2,100 m; in Central and Eastern Nepal)	Nepal , Bangladesh, Cambodia, China, India, East Himalaya, Borneo, Jawa and Sumatra (Indonesia), Laos, Malaya, Myanmar, Philippines, Thailand, Tibet (China), Vietnam

Note: *Terminalia alata* B. Heyne ex Roth synonymous *Terminalia elliptica* Willd.

Source: http://www.efloras.org/flora_page.aspx?flora_id=110

<https://powo.science.kew.org/>

Annex II
Detail Descriptions of the Sampled Trees

a) *Alnus nepalensis*

SN	Province	District	Tree ID	Management type	Longitude	Latitude	Elevation (m asl)	Slope (%)	Aspect (Degree)	DBH (cm)	Height (m)	Stem Volume (m ³)	Total Biomass (Kg)	Stump Volume (m ³)	Stump Biomass (Kg)	Stump Volume %	Stump Biomass %
1	K	Bhojpur	135An007	CF	504784	3008541	1959	18	154	45.8	28.7	2.6	1256.293	0.089	34.295	3.41	2.73
2	K	Bhojpur	138An010	CF	504769	3008565	1985	20	184	33.9	29.1	1.1881	601.795	0.052	20.445	4.38	3.4
3	K	Bhojpur	139An011	CF	504970	3008629	1789	30	224	24.5	20.3	0.4849	203.067	0.022	8.179	4.49	4.03
4	K	Bhojpur	140An012	CF	504769	3008564	1970	38	187	75.8	32.3	5.0022	2524.408	0.19	65.904	3.8	2.61
5	K	Dhankuta	056An003	CF	533071	2985675	1230	40	275	57.2	27.5	2.8883	1968.974	0.102	45.312	3.53	2.3
6	K	Dhankuta	057An004	CF	600185	2948171	1342	25	260	36.4	28.75	1.3421	890.547	0.037	20.272	2.78	2.28
7	K	Dhankuta	058An005	CF	533143	2985664	1401	48	267	17.8	18.8	0.2356	122.59	0.009	4.038	3.61	3.29
8	K	Dhankuta	060An006	CF	533097	2985658	1386	45	250	44.7	27.5	1.995	1246.832	0.06	26.987	3	2.16
9	K	Ilam	048An001	CF	591581	2978488	1305	50	270	37.3	31.6	1.5759	1060.385	0.034	17.397	2.18	1.64
10	K	Ilam	054An002	CF	591724	2978753	1281	85	345	49	36.6	3.2795	2053.942	0.064	32.4	1.95	1.58
11	K	Khotang	159An013	CF	472687	3013699	1852	30	107	29.9	24.1	0.7584	424.274	0.028	13.811	3.7	3.26
12	K	Okhaldhunga	172An015	CF	455851	3020118	1109	70	40	39	34	1.9824	1076.004	0.046	20.941	2.3	1.95
13	K	Solukhumbu	191An016	CF	457129	3034727	2297	82	336	27.4	18.6	0.4971	220.107	0.02	8.612	4.1	3.91
14	K	Solukhumbu	192An017	CF	457469	3034347	2253	100	275	34.2	20.3	0.8326	399.874	0.045	17.371	5.43	4.34
15	B	Dhading	338An025	GMF	303276	3095455	1458	44	315	16.1	15.8	0.1361	69.571	0.008	3.792	6.12	5.45
16	B	Kavrepalanchok	253An021	CF	354383	3062965	1863	11	125	43.4	28.8	1.8865	952.647	0.061	25.16	3.21	2.64
17	B	Kavrepalanchok	309An241	CF	354302	3062365	1674	60	330	38.2	26.9	1.7165	1007.696	0.046	22.872	2.67	2.27

SN	Province	District	Tree ID	Management type	Longitude	Latitude	Elevation (m asl)	Slope (%)	Aspect (Degree)	DBH (cm)	Height (m)	Stem Volume (m ³)	Total Biomass (Kg)	Stump Volume (m ³)	Stump Biomass (Kg)	Stump Volume %	Stump Biomass %
18	B	Kavrepalanchok	309An242	CF	354315	3062413	1854	25	307	34.9	28.1	1.2773	617.095	0.041	18.271	3.24	2.96
19	B	Nuwakot	283An023	PF	318492	3079496	953	40	290	16.6	18.34	0.1877	107.754	0.009	3.989	5.02	3.7
20	B	Nuwakot	320An024	PF	318490	3079498	936	50	290	20.6	18.32	0.2665	124.843	0.013	4.135	5.05	3.31
21	B	Ramechhap	198An018	CF	416963	3042490	1329	10	274	36.6	26.3	1.2442	589.712	0.042	20.348	3.4	3.45
22	G	Baglung	397An028	PF	740500	3128643	1780	14	29	24.8	17.6	0.421	224.175	0.021	9.328	4.97	4.16
23	G	Baglung	400An029	PF	740620	3128756	1850	32	346	16.4	11.7	0.1185	55.94	0.007	2.958	6.16	5.29
24	G	Gorkha	393An027	PF	283722	3124117	2420	10	57	32.8	22.4	0.8674	384.919	0.04	13.88	4.66	3.61
25	G	Gorkha	446An050	PF	304069	3150966	2330	21	176	24	28.3	0.5759	218.618	0.016	5.597	2.83	2.56
26	G	Gorkha	447An051	PF	303948	3150980	2320	41	208	18.9	20.3	0.2926	121.084	0.011	4.199	3.86	3.47
27	G	Kaski	406An031	PA	216041	3129568	1570	47	143	7.4	10.7	0.0273	15.353	0.002	0.847	6.84	5.52
28	G	Kaski	409An032	PA	216040	3129708	1620	40	30	57.9	23.1	2.6759	1769.593	0.117	45.263	4.38	2.56
29	G	Kaski	410An033	PA	216047	3129709	1620	39	309	83.4	25.1	4.55	3268.386	0.281	102.021	6.19	3.12
30	G	Kaski	412An034	CF	788912	3129772	1070	30	148	17	20.5	0.2604	133.227	0.009	4.48	3.62	3.36
31	G	Lamjung	392An026	CF	248074	3133630	1880	32	56	61	22.9	2.3246	1206.842	0.106	42.132	4.56	3.49
32	G	Lamjung	433An040	CF	248129	3133052	1990	35	45	64.8	32.6	4.7653	2199.161	0.133	61.23	2.78	2.78
33	G	Lamjung	434An041	CF	248142	3133056	2000	35	42	45.2	30.9	2.3088	1008.738	0.072	27.789	3.12	2.75
34	G	Lamjung	435An042	CF	248124	3153065	2000	38	44	55.5	26.1	2.5488	1260.78	0.105	48.026	4.13	3.81
35	G	Lamjung	437An044	CF	247920	3133170	1995	37	22	29.9	28.1	0.9649	356.622	0.029	10.486	2.97	2.94
36	G	Lamjung	444An048	CF	255484	3146113	1900	34	52	26.1	22.7	0.5891	262.815	0.019	7.967	3.18	3.03

SN	Province	District	Tree ID	Management type	Longitude	Latitude	Elevation (m asl)	Slope (%)	Aspect (Degree)	DBH (cm)	Height (m)	Stem Volume (m ³)	Total Biomass (Kg)	Stump Volume (m ³)	Stump Biomass (Kg)	Stump Volume %	Stump Biomass %
37	G	Myagdi	438An045	CF	748394	3142146	1880	25	48	34.9	22.9	1.0014	646.445	0.048	25.413	4.74	3.93
38	G	Myagdi	440An046	CF	748328	3142192	1880	29	48	47.3	31.1	2.2361	1273.171	0.067	31.663	3	2.49
39	G	Myagdi	443An047	CF	748317	3142214	1880	32	48	59.7	28.2	3.1233	1912.65	0.122	47.568	3.9	2.49
40	L	Rolpa	418An037	CF	664626	3130231	1888	42	27	66.6	25.6	3.1404	1969.272	0.131	66.956	4.16	3.4
41	L	Rolpa	419An038	CF	664622	3130251	1950	39	175	15.3	10.6	0.088	46.749	0.006	2.302	7.03	4.92
42	L	Rolpa	421An039	CF	664650	3130287	1920	35	109	8.8	4.5	0.0203	13.917	0.002	1.081	12.31	7.77
43	L	Rolpa	445An049	GMF	658845	3147990	2260	45	285	40.6	21.9	1.1706	618.828	0.053	21.613	4.52	3.49
44	KR	Jajarkot	511An058	CF	595268	3189480	2080	40	180	22.7	12.5	0.2256	108.625	0.016	7.122	7.06	6.56
45	KR	Jajarkot	512An059	CF	595315	3189491	2122	45	180	37.1	14.9	0.5785	438.958	0.042	18.459	7.22	4.21
46	KR	Surkhet	457An053	CF	583589	3168971	1910	44	300	25.4	11.7	0.2418	197.193	0.019	8.716	7.8	4.42
47	KR	Surkhet	460An054	CF	583611	3169020	1879	36	353	15	10.2	0.0806	51.464	0.006	2.808	7.3	5.46
48	KR	Surkhet	463An056	PF	583823	3169351	1650	42	47	10.1	6.9	0.0297	18.11	0.003	1.205	9.95	6.65
49	KR	Surkhet	464An057	PF	583803	3169396	1639	32	31	9.7	7.7	0.0356	22.797	0.004	1.729	10.68	7.59
50	SP	Doti	548An060	CF	502889	3240342	1811	30	0	29.3	23.7	0.7781	324.021	0.028	10.917	3.65	3.37
51	SP	Doti	549An061	CF	502883	3240353	1852	30	324	53.6	27.6	2.5769	1725.703	0.091	41.496	3.51	2.4
52	SP	Doti	550An062	CF	502859	3240353	1842	35	25	71.2	28.8	4.6959	2882.352	0.158	69.595	3.37	2.41

b) *Castanopsis* spp.

SN	Province	District	Tree ID	Management type	Longitude	Latitude	Elevation (m asl)	Slope (%)	Aspect (Degree)	DBH (cm)	Height (m)	Stem Volume (m ³)	Total Biomass (kg)	Stump Volume (m ³)	Stump Biomass (kg)	Stump Volume %	Stump Biomass %
1	K	Bhojpur	125Cs014	CF	504322	3008146	2009	50	328	18.1	11.4	0.1358	99.779	0.009	3.911	6.26	3.92
2	K	Bhojpur	126Cs015	CF	504316	3008155	1970	70	310	18.7	12.8	0.1737	149.592	0.009	3.986	5.43	2.66
3	K	Bhojpur	128Cs016	CF	504415	3008296	2014	55	30	7.8	8.3	0.0222	17.644	0.002	0.831	7.49	4.71
4	K	Bhojpur	130Cs017	CF	504429	3008319	1950	45	270	24.5	12.1	0.286	272.809	0.018	7.293	6.14	2.67
5	K	Bhojpur	131Cs018	CF	504412	3008383	1990	50	316	33.1	15.75	0.5706	551.595	0.033	17.079	5.81	3.1
6	K	Bhojpur	132Cs019	CF	504458	3008442	1972	70	310	32.6	19	0.7612	520.321	0.031	15.165	4.01	2.91
7	K	Bhojpur	133Cs020	CF	504814	3008532	2068	70	300	49	18.8	1.5107	1394.267	0.06	29.738	3.98	2.13
8	K	Bhojpur	134Cs021	CF	504814	3008532	2072	50	175	44.5	17.8	1.317	1166.322	0.055	24.939	4.21	2.14
9	K	Ilam	043Cs001	CF	591525	2978489	1340	45	270	37.5	22.5	1.1785	828.367	0.042	17.374	3.53	2.1
10	K	Ilam	044Cs002	CF	591519	2978500	1320	32	315	18	18.6	0.2249	114.128	0.012	4.631	5.16	4.06
11	K	Ilam	047Cs004	CF	591538	2978496	1339	52	295	10	12.4	0.0481	23.667	0.003	1.164	6.04	4.92
12	K	Ilam	049Cs005	CF	591510	2978490	1342	30	325	17.6	14.6	0.1627	100.443	0.009	4.213	5.79	4.19
13	K	Ilam	051Cs006	CF	591517	2978506	1321	33	315	23.3	20.6	0.4392	228.038	0.015	6.316	3.43	2.77
14	K	Ilam	053Cs007	CF	591542	2978523	1297	25	260	46	18.8	1.5173	1110.991	0.083	35.766	5.46	3.22
15	K	Khotang	152Cs029	CF	484032	3011275	1884	39	23	25.2	16.5	0.3753	322.364	0.018	7.456	4.78	2.31
16	K	Khotang	153Cs030	CF	484106	3011280	1934	38	291	42.7	12.5	0.761	1120.54	0.057	31.548	7.46	2.82
17	K	Khotang	154Cs031	CF	483846	3011247	1858	35	280	40.6	18.5	0.9189	778.452	0.054	23.789	5.83	3.06
18	K	Khotang	161Cs032	CF	477924	3016105	2268	70	265	76.4	20.5	2.7053	2809.507	0.201	103.766	7.42	3.69
19	K	Okhaldhunga	173Cs033	CF	458259	3020597	1139	45	20	26.9	14.3	0.3668	302.113	0.025	12.888	6.87	4.27

SN	Province	District	Tree ID	Management type	Longitude	Latitude	Elevation (m asl)	Slope (%)	Aspect (Degree)	DBH (cm)	Height (m)	Stem Volume (m ³)	Total Biomass (Kg)	Stump Volume (m ³)	Stump Biomass (Kg)	Stump Volume %	Stump Biomass %
20	K	SoluKhumbu	194Cs035	CF	465736	3035534	2274	40	190	30.6	17.8	0.5872	484.195	0.029	12.117	4.94	2.5
21	K	Terhathum	105Cs008	CF	552114	3002390	1701	20	240	30.9	14.3	0.5093	394.454	0.04	19.205	7.78	4.87
22	K	Terhathum	106Cs009	CF	552102	3002409	1713	15	251	28.6	12.38	0.3591	326.6	0.025	11.976	7.02	3.67
23	K	Terhathum	107Cs010	CF	552117	3002491	1745	62	87	17	15.7	0.1702	102.605	0.011	5.796	6.58	5.65
24	K	Terhathum	109Cs011	CF	552090	3002505	1761	62	94	9.8	8.8	0.044	36.854	0.003	1.391	6.13	3.77
25	K	Terhathum	110Cs012	CF	552072	3002455	1654	12	235	17.8	9.95	0.1373	134.325	0.01	4.656	7	3.47
26	B	Dhading	324Cs042	CF	279602	3092279	282	40	300	5.4	6.2	0.0065	6.625	0.001	0.349	13.05	5.28
27	B	Dhading	325Cs043	CF	279343	3092281	702	57	263	28.4	18.2	0.552	475.368	0.027	13.63	4.88	2.87
28	B	Dhading	334Cs044	PF	299440	3035412	1390	70	40	31.4	15.6	0.4694	612.017	0.027	15.177	5.8	2.48
29	B	Dhading	343Cs045	PF	299367	3095559	1936	65	250	6.1	4.55	0.0097	7.04	0.001	0.478	11.56	6.78
30	B	Nuwakot	295Cs040	CF	337277	3090387	977	97	150	26.1	13.15	0.2888	437.481	0.02	10.95	6.91	2.5
31	B	Nuwakot	321Cs041	CF	337012	3090709	921	75	277	31.6	19.2	0.7414	539.704	0.031	16.008	4.16	2.97
32	B	Sindhuli	143Cs023	CF	389219	3009745	603	75	88	24	19.4	0.3918	308.026	0.022	12.579	5.63	4.08
33	B	Sindhuli	145Cs024	CF	389267	3009729	573	60	186	48.5	23.5	1.8667	1680.383	0.066	32.952	3.53	1.96
34	B	Sindhuli	146Cs025	CF	389295	3009779	586	57	121	17.4	15.7	0.1677	124.091	0.009	4.689	5.13	3.78
35	B	Sindhuli	147Cs026	CF	389217	3009688	553	45	175	67.1	29.4	4.6382	3745.229	0.154	79.728	3.32	2.13
36	B	Sindhuli	148Cs027	CF	389146	3009601	542	35	270	52.6	27.5	2.3217	1771.634	0.095	46.37	4.08	2.62
37	B	Sindhuli	149Cs028	CF	389124	3009697	544	35	319	55.7	26.46	2.5939	2342.193	0.098	52.42	3.77	2.24
38	G	Gorkha	355Cs049	CF	251464	3101115	570	32	142	26.9	18.1	0.3396	257.305	0.019	11.887	5.71	4.62
39	G	Gorkha	356Cs050	Indeterminate	251477	3101116	570	39	222	41.8	19.9	1.081	1273.669	0.044	25.43	4.07	2

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40	G	Gorkha	357Cs051	CF	251477	3101118	560	10	274	58.2	23	1.916	1334.503	0.088	47.746	4.58	3.58
41	G	Gorkha	358Cs052	CF	251442	3101133	540	27	204	32	17.9	0.5495	559.31	0.028	15.817	5.07	2.83
42	G	Gorkha	359Cs053	CF	251326	3101151	501	39	204	64.7	20.2	2.1434	2299.226	0.103	55.224	4.82	2.4
43	G	Gorkha	361Cs054	CF	251326	3101151	502	37	241	12.2	8.5	0.0397	36.263	0.004	2.009	8.98	5.54
44	G	Myagdi	439Cs060	CF	748368	3142177	1890	42	32	28.6	15.7	0.4666	443.882	0.02	10.881	4.22	2.45
45	G	Tanahu	344Cs046	CF	235659	3097379	517	50	295	49	25.5	2.2378	1929.152	0.078	42.759	3.48	2.22
46	G	Tanahu	345Cs047	CF	235636	3097398	551	25	285	63.2	24.4	2.3368	3314.087	0.108	55.996	4.63	1.69
47	G	Tanahu	371Cs055	CF	235650	3109099	936	40	313	14.2	12.4	0.104	78.278	0.008	3.99	7.42	5.1
48	G	Tanahu	372Cs056	CF	235665	3108873	823	40	120	44.9	13.25	0.5673	957.048	0.05	24.187	8.79	2.53
49	G	Tanahu	373Cs057	CF	235842	3109235	915	60	105	27.5	13.8	0.3543	330.296	0.02	10.373	5.59	3.14
50	L	Arghakhanchi	288Cs038	CF	697945	3079892	1080	28	166	35	12.1	0.4222	336.628	0.045	24.836	10.56	7.38
51	L	Palpa	290Cs039	CF	750617	3082149	870	25	7	11.3	10.7	0.0517	32.7	0.004	1.882	7.35	5.76
52	L	Roelpa	396Cs059	CF	681075	3128176	1882	35	106	32.2	9.8	0.3814	385.59	0.029	15.041	7.57	3.9

c) Lagerstroemia parviflora

SN	Province	District	Tree ID	Management type	Longitude	Latitude	Elevation (m asl)	Slope (%)	Aspect (Degree)	DBH (cm)	Height (m)	Stem Volume (m ³)	Total Biomass (Kg)	Stump Volume (m ³)	Stump Biomass (Kg)	Stump Volume %	Stump Biomass %
1	K	Morang	008Lp001	GMF	549968	2949940	160	0	0	23.7	20.4	0.4295	296.12	0.016	9.259	3.82	3.13
2	K	Morang	016Lp003	GMF	549984	2949966	161	0	0	14.2	13.5	0.0965	57.507	0.006	2.639	5.72	4.59
3	K	Morang	018Lp004	GMF	549906	2949930	161	0	0	8.6	9.7	0.0317	15.03	0.002	0.92	6.57	6.12
4	K	Morang	019Lp005	GMF	549887	2950088	168	0	0	37.6	26.5	1.4821	952.814	0.043	31.199	2.9	3.27
5	K	Morang	024Lp008	GMF	549920	2950086	174	0	0	41.4	25.1	1.3885	1239.524	0.061	35.186	4.36	2.84
6	K	Sunsari	026Lp009	CF	532958	2959584	223	0	0	9.8	12.5	0.0484	28.563	0.003	1.517	6	5.31
7	K	Sunsari	028Lp011	CF	532836	2959715	174	0	0	23.9	18.9	0.3489	227.616	0.019	10.695	5.49	4.7
8	K	Sunsari	029Lp012	CF	532838	2959716	190	0	0	15.6	14.8	0.129	57.764	0.008	3.206	6.25	5.55
9	K	Udayapr	038Lp013	CF	459639	2974193	542	20	100	14	11.65	0.0857	52.457	0.006	3.175	7.49	6.05
10	M	Dhanusa	075Lp016	CF	396906	2989401	368	60	160	26.6	18.6	0.4266	346.986	0.023	12.368	5.38	3.56
11	M	Mahottari	070Lp015	GMF	380798	2986103	173	0	0	11.8	8.7	0.0546	34.963	0.007	3.076	12.18	8.8
12	M	Rautahat	114Lp022	CFM	325190	3002914	117	0	0	46.9	26.45	1.8696	1393.467	0.092	54.87	4.92	3.94
13	M	Rautahat	117Lp023	CFM	325308	3002996	133	0	0	22.2	17.45	0.3113	185.202	0.013	5.926	4.11	3.2
14	M	Rautahat	120Lp025	CFM	325255	3003175	119	0	0	51.7	29.3	2.8989	2061.283	0.09	54.2	3.1	2.63
15	M	Sarlahi	081Lp017	CFM	352833	2990590	115	0	0	25.8	23.8	0.5877	351.315	0.021	10.149	3.49	2.89
16	M	Sarlahi	090Lp020	CFM	352902	2990751	99	0	0	19.4	18.9	0.2861	202.147	0.012	6.672	4.21	3.3
17	M	Sarlahi	095Lp021	CF	370390	2993164	182	0	0	40.2	27	1.3633	1051.664	0.066	32.932	4.84	3.13

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18	B	Chitwan	227Lp036	CF	266107	3060800	377	40	290	20	17.9	0.2227	156.757	0.011	5.635	5.03	3.59
19	B	Dhading	323Lp046	CF	279336	3092326	730	60	275	7.1	5.5	0.0149	10.254	0.002	0.766	13.1	7.47
20	B	Makwanpur	181Lp027	CF	317007	3025750	480	44	230	43.2	24.4	1.286	1392.482	0.071	44.468	5.5	3.19
21	B	Makwanpur	182Lp028	CF	317255	3025528	482	50	180	53.4	27.2	2.6255	1889.508	0.105	54.2	4	2.87
22	B	Makwanpur	184Lp029	CF	317088	3025746	519	19	213	58.1	26.5	3.0685	2470.512	0.118	81.569	3.86	3.3
23	B	Makwanpur	185Lp030	CF	316748	3025906	457	55	123	33.5	22.4	0.7876	757.439	0.042	23.512	5.35	3.1
24	B	Sindhuli	085Lp018	CF	406142	2990684	320	0	0	14.5	10.4	0.0769	55.726	0.006	3.324	7.46	5.96
25	B	Sindhuli	088Lp019	CF	406209	2990717	316	0	0	24.1	16	0.3368	276.78	0.016	9.079	4.69	3.28
26	G	Nawalparasi (E)	211Lp034	CF	790115	3057750	190	0	0	9.4	10.7	0.0415	21.105	0.003	1.349	7.38	6.39
27	G	Nawalparasi (E)	230Lp037	BZCF	218268	3061699	190	0	0	12.6	9.9	0.0786	43.122	0.005	2.166	5.79	5.02
28	G	Nawalparasi (E)	241Lp038	GMF	794149	3061893	201	30	169	16.2	17.2	0.1526	90.262	0.01	5.787	6.87	6.41
29	G	Tanahu	368Lp047	RF	235742	3108822	836	45	190	15.3	14.46	0.1376	98.526	0.008	4.63	5.49	4.7
30	G	Tanahu	375Lp048	LHF	243934	3109413	809	11	240	12.9	8.53	0.0363	26.096	0.004	2.4	10.3	9.2
31	L	Arghakhanchi	308Lp045	GMF	693710	3087688	810	35	140	9.7	9.05	0.0364	29.314	0.004	2.608	10.77	8.9
32	L	Bardiya	428Lp050	PA	547595	3131005	160	0	0	33.2	21.8	0.808	779.043	0.036	23.626	4.41	3.03
33	L	Bardiya	429Lp051	BZCF	547615	3131019	170	0	0	26.8	20.9	0.4632	393.556	0.025	15.676	5.34	3.98
34	L	Dang	271Lp042	GMF	653674	3070515	385	35	99	33.8	24.5	1.0882	1006.029	0.037	24.926	3.4	2.48
35	L	Dang	298Lp043	CF	669792	3083225	331	20	190	12.6	11.3	0.0604	60.997	0.006	3.295	6.86	5.4

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36	L	Dang	301Lp044	CF	669819	3083316	343	30	10	15.5	8.3	0.0836	67.958	0.01	5.483	11.61	8.07
37	L	Kapilbastu	263Lp039	CF	714888	3070068	200	0	0	54.2	28.3	2.4742	1845.681	0.094	56.928	3.78	3.08
38	L	Kapilbastu	265Lp040	CF	714731	3069834	184	0	0	33.8	25.3	0.9065	663.914	0.05	30.029	5.55	4.52
39	L	Kapilbastu	266Lp041	CF	741871	3069902	161	0	0	33.2	20.2	0.5353	436.344	0.027	13.327	5.06	3.05
40	L	Parasi	206Lp031	CF	770229	3057205	144	0	0	28.8	20.1	0.7428	501.975	0.026	15.181	3.56	3.02
41	L	Parasi	207Lp032	CF	770206	3057222	145	0	0	18.2	15.9	0.2209	120.644	0.01	4.712	4.53	3.91
42	L	Parasi	210Lp033	CF	770707	3057407	172	0	0	37.3	21.8	0.913	667.012	0.045	27.249	4.95	4.09
43	SP	Kailali	486Lp053	CF	481651	3177957	196	0	0	25.4	15.1	0.331	251.199	0.017	9.301	5.27	3.7
44	SP	Kailali	494Lp054	CF	478635	3181821	196	0	0	31.7	18.3	0.5398	418.845	0.03	15.613	5.63	3.73
45	SP	Kailali	497Lp056	CF	478662	3182151	214.1	0	0	11.8	8.4	0.0389	22.732	0.004	1.787	11.04	7.86
46	SP	Kailali	503Lp057	CF	465576	3184402	176	0	0	44.3	20.3	1.2484	925.895	0.066	41.758	5.32	4.51

d) *Pinus roxburghii*

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1	K	Dhankuta	059Pr001	CF	533081	2985689	1382	37	257	27.6	19.55	0.6018	341.483	0.02	10.239	3.32	3
2	K	Dhankuta	061Pr002	CF	533094	2985691	1401	35	233	43.5	24.1	1.6733	923.287	0.047	21.93	2.8	2.38
3	K	Dhankuta	062Pr003	CF	533004	2985730	1371	40	235	30.3	26.4	0.9502	455.771	0.024	9.77	2.56	2.14
4	K	Dhankuta	064Pr004	CF	533057	2985793	1406	70	225	19.7	17.3	0.2395	118.163	0.01	5.069	4.17	4.29
5	K	Khotang	157Pr011	CF	466822	3011966	1400	40	189	91.2	36.4	8.5778	7039.863	0.216	138.534	2.52	1.97
6	K	Khotang	327Pr038	CF	466701	3012110	1440	37	345	73	27.65	5.804	4183.082	0.139	56.789	2.4	1.36
7	K	Okhaldhunga	170Pr017	CF	455834	3020140	1160	70	130	32.5	23.3	0.9827	666.034	0.031	17.393	3.11	2.61
8	K	Okhaldhunga	171Pr018	CF	458062	3020231	1214	60	180	43.4	26.3	1.9081	1269.257	0.052	31.342	2.75	2.47
9	K	Sankhuwasabha	162Pr012	CF	527534	3016338	1330	36	204	41.5	18.7	1.3011	818.437	0.053	17.766	4.07	2.17
10	K	Sankhuwasabha	163Pr013	CF	527602	3016359	1344	39	234	6.7	7.2	0.0141	10.544	0.002	0.688	10.69	6.52
11	K	Sankhuwasabha	164Pr014	CF	527531	3016379	1348	30	187	32.7	19.4	0.8225	509.815	0.032	16.467	3.86	3.23
12	K	Sankhuwasabha	168Pr016	CF	527475	3016394	1339	35	202	25.7	17.8	0.4766	321.489	0.023	11.634	4.75	3.62
13	K	Terathum	099Pr005	CF	552670	3001440	1593	30	195	43.7	28.4	2.0443	1302.544	0.048	26.699	2.34	2.05
14	K	Terathum	104Pr009	CF	552660	3001432	1622	20	260	36.2	26.9	1.3331	848.695	0.04	25.744	2.99	3.03
15	K	Terhathum	101Pr007	CF	552633	3001418	1663	21	270	17.5	14.9	0.188	93.177	0.01	4.474	5.22	4.8
16	K	Terhathum	103Pr008	CF	552668	3001426	1631	21	258	26	24.7	0.6116	292.118	0.02	10.409	3.31	3.56
17	B	Kavrepalanchok	200Pr022	CF	370188	3045728	1084	60	120	23.8	10.3	0.2226	179.34	0.018	7.643	8.18	4.26

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18	B	Kavrepalanchok	201Pr023	CF	370179	3045828	1060	80	50	42	17.8	1.2967	983.436	0.051	23.115	3.96	2.35
19	B	Kavrepalanchok	203Pr024	CF	373272	3049523	1300	37	98	26.1	21	0.534	300.055	0.018	9.608	3.46	3.2
20	B	Kavrepalanchok	244Pr025	CF	362490	3062298	1031	50	56	24.7	14.2	0.3523	258.527	0.017	8.137	4.91	3.15
21	B	Kavrepalanchok	245Pr026	CF	362484	3062309	1028	47	84	34.6	16.1	0.7411	667.278	0.033	15.973	4.49	2.39
22	B	Kavrepalanchok	249Pr027	CF	354256	3063005	1913	45	150	52	24.6	2.2937	1363.996	0.083	43.261	3.61	3.17
23	B	Kavrepalanchok	251Pr028	CF	354332	3062643	1860	60	210	30.1	15.2	0.522	261.7	0.025	12.314	4.86	4.71
24	B	Kavrepalanchok	318Pr037	CF	373263	3049548	1323	39	88	12.1	14.3	0.075	42.356	0.004	1.77	5.39	4.18
25	B	Nuwakot	331Pr040	CF	315533	3095382	1559	65	175	63.6	32.6	5.4401	4342.021	0.112	74.46	2.06	1.71
26	B	Nuwakot	333Pr042	CF	315552	3095401	1555	35	168	14.1	8.3	0.0715	52.771	0.007	3.664	9.75	6.94
27	B	Nuwakot	335Pr043	CF	315254	3095498	1574	55	178	27.7	15.65	0.4929	280.551	0.021	9.18	4.36	3.27
28	B	Nuwakot	339Pr044	CF	315419	3095492	1601	35	302	23.1	13.75	0.287	155.289	0.016	8.962	5.64	5.77
29	B	Nuwakot	340Pr045	CF	315428	3095492	1595	42	58	42.1	21.2	1.3502	917.555	0.049	23.781	3.6	2.59
30	B	Nuwakot	342Pr046	CF	315177	3095485	1592	55	173	9.9	7.55	0.0368	20.386	0.004	1.65	10.65	8.09
31	B	Ramechhap	252Pr029	CF	415262	3040693	1147	34	38	52	25.8	2.519	2042.203	0.081	45.038	3.22	2.21
32	B	Ramechhap	330Pr039	CF	415251	3040693	1149	40	347	65.6	25.6	4.1947	3208.993	0.117	52.239	2.78	1.63
33	G	Parbat	402Pr059	CF	763342	3128950	1810	28	66	43.5	22.3	1.2506	942.396	0.052	30.779	4.14	3.27
34	G	Parbat	403Pr060	CF	763379	3129012	1790	24	92	51.6	26.9	2.2893	1632.041	0.079	38.345	3.46	2.35
35	G	Parbat	404Pr061	CF	763391	3129050	1800	17	79	21.8	18.1	0.212	145.114	0.014	7.501	6.84	5.17

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36	G	Parbat	405Pr062	CF	763394	3129069	1790	19	81	47.1	24	1.7902	1218.471	0.062	25.511	3.48	2.09
37	L	Arghakhanchi	311Pr034	GMF	693635	3087763	859	39	176	8.9	6.2	0.0253	17.129	0.002	1.187	9.31	6.93
38	L	Arghakhanchi	284Pr030	CF	697729	3079645	1030	32	130	42.4	18.75	1.2963	996.01	0.045	25.462	3.44	2.56
39	L	Arghakhanchi	285Pr031	CF	697662	3079705	1095	38	175	20.2	15.6	0.2965	189.129	0.013	6.95	4.39	3.67
40	L	Arghakhanchi	310Pr033	GMF	693662	3087719	840	29	179	11.8	8.95	0.0545	41.382	0.005	3.053	8.96	7.38
41	L	Arghakhanchi	312Pr035	GMF	693630	3087787	880	45	39	39.1	19	1.2138	1089.268	0.055	38.06	4.55	3.49
42	L	Arghakhanchi	314Pr036	GMF	694282	3088413	890	40	37	55	22.5	2.4139	1691.283	0.081	45.71	3.36	2.7
43	L	Dang	364Pr049	GMF	652996	3105553	1148	40	10	40	14.8	0.8883	795.637	0.045	26.937	5.11	3.39
44	L	Gulmi	352Pr047	CF	736738	3100474	1390	22	150	57.4	21.8	2.6385	1530.856	0.09	44.367	3.42	2.9
45	L	Gulmi	354Pr048	CF	736707	3100667	1380	26	322	45.4	24	1.5612	862.34	0.064	34.478	4.08	4
46	L	Gulmi	385Pr052	CF	721014	3120583	1510	19	240	31.9	21.9	0.9187	476.953	0.027	15.079	2.93	3.16
47	L	Gulmi	387Pr054	CF	720987	3120603	1510	18	245	26.8	20.7	0.6221	323.143	0.022	10.147	3.52	3.14
48	L	Rolpa	377Pr050	CF	657105	3110546	1350	35	27	22.9	12.7	0.2926	208.135	0.015	7.78	5.11	3.74
49	L	Rolpa	384Pr051	CF	649751	3118675	1811	45	170	47.7	22.9	2.0841	1213.875	0.059	26.312	2.84	2.17
50	L	Rolpa	388Pr055	CF	660373	3123320	1050	35	328	41.6	25.7	1.4542	1029.528	0.052	27.391	3.59	2.66
51	L	Rolpa	389Pr056	CF	660551	3123371	1070	25	2	10.4	7.9	0.0408	20.787	0.004	1.14	9.46	5.48
52	L	Rolpa	390Pr057	CF	660559	3123397	1020	35	311	34.3	24.05	1.0081	605.93	0.037	19.108	3.63	3.15
53	L	Rolpa	391Pr058	CF	660418	3123421	100	42	1	59.9	30.1	4.1096	2678.065	0.103	62.137	2.51	2.32

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54	L	Rolpa	417Pr063	CF	640630	3129973	1555	35	240	26.7	19.7	0.4979	265.001	0.021	11.43	4.26	4.31
55	L	Rolpa	423Pr065	CF	660740	3130330	1607	35	35	60.7	26.1	3.9532	3059.219	0.113	63.363	2.85	2.07
56	KR	Dailekh	491Pr077	CF	562364	3180289	1234	15	254	35.5	18.7	0.9536	667.4	0.036	19.277	3.8	2.89
57	KR	Dailekh	492Pr078	CF	562319	3180314	1281	30	245	18.4	13.7	0.1716	85.35	0.009	3.91	5.49	4.58
58	KR	Dailekh	493Pr079	CF	562515	3180765	1125	40	335	56.1	25.9	3.38	2234.123	0.088	53.927	2.6	2.41
59	KR	Dailekh	518Pr080	CF	558678	3196481	1091	25	182	13.3	8	0.0607	33.292	0.006	2.659	9.09	7.99
60	KR	Dailekh	519Pr081	CF	559131	3196532	1172	25	255	54.5	25.5	2.6681	1975.652	0.109	63.431	4.08	3.21
61	KR	Jajarkot	467Pr070	CF	603491	3169683	928	40	95	27	13.9	0.3163	299.14	0.024	11.328	7.44	3.79
62	KR	Jajarkot	468Pr071	CF	603419	3169713	904	30	135	32.3	15.4	0.5614	357.963	0.028	11.805	5	3.3
63	KR	Jajarkot	473Pr075	CF	603376	3170015	899	25	100	12.9	7.7	0.0533	31.203	0.005	1.466	8.66	4.7
64	KR	Jajarkot	476Pr076	CF	612116	3170131	1209	40	165	9	4.3	0.019	11.479	0.003	1.119	13.93	9.74
65	KR	Mugu	558Pr107	BZCF	599787	3273915	1648	35	315	64.2	23.4	2.856	2506.475	0.11	63.96	3.86	2.55
66	KR	Mugu	559Pr108	BZCF	599693	3273810	1580	45	320	52.2	21.9	2.154	1823.042	0.08	42.982	3.72	2.36
67	KR	Mugu	560Pr109	BZCF	599700	3273762	1642	60	320	37.5	14.8	0.6281	581.872	0.04	19.982	6.4	3.43
68	KR	Mugu	561Pr110	BZCF	599641	3273851	1586	40	320	7.5	2.5	0.0108	7.056	0.003	0.915	24.98	12.97
69	KR	Mugu	562Pr111	BZCF	599730	3273864	1625	35	350	22	8.5	0.1509	124.717	0.017	9.031	11.38	7.24
70	KR	Rukum (W)	466Pr069	CF	619756	3169626	902	20	250	29.4	15.9	0.5002	335.225	0.025	11.836	4.98	3.53
71	KR	Rukum (W)	469Pr072	CF	619696	3169667	889	60	146	42.6	24.5	1.5402	1142.706	0.052	24.629	3.38	2.16

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72	KR	Rukum (W)	470P073	CF	619726	3169876	925	25	135	17.3	7.7	0.1073	54.268	0.009	3.891	8.78	7.17
73	KR	Surkhet	458P066	CF	583413	3168999	1877	45	2	33.7	13.4	0.5497	328.813	0.035	15.774	6.32	4.8
74	KR	Surkhet	459P067	CF	583603	3169018	1870	45	357	47.5	15.2	1.3699	1186.55	0.06	29.949	4.37	2.52
75	KR	Surkhet	461P068	CF	583916	3169021	1681	44	54	67.9	26	4.3853	3045.246	0.134	67.868	3.05	2.23
76	SP	Achham	534P086	CF	522273	3223473	1428	15	68	29.9	13.4	0.4699	376.568	0.027	11.725	5.73	3.11
77	SP	Achham	535P087	CF	522014	3223497	1456	85	222	36.3	18.9	0.9887	587.998	0.035	19.22	3.53	3.27
78	SP	Achham	536P088	CF	522277	3223507	1434	20	58	7.2	3.8	0.012	5.569	0.002	0.496	15.21	8.91
79	SP	Achham	538P090	CF	510415	3226999	1601	35	15	13.5	5.6	0.0482	29.03	0.006	2.752	13.31	9.48
80	SP	Achham	539P091	CF	510598	3227093	1675	65	29	45.2	21.5	1.5795	771.833	0.054	22.709	3.39	2.94
81	SP	Achham	540P092	CF	510551	3227110	1686	55	65	39.7	20.5	1.2843	750.833	0.043	21.853	3.36	2.91
82	SP	Dadeldhura	529P084	CF	450387	3214516	1129	30	23	76.4	34	6.4495	3963.846	0.168	94.406	2.61	2.38
83	SP	Dadeldhura	530P085	CF	450371	3214596	1117	30	35	70.4	28.2	4.5068	3018.145	0.143	82.337	3.17	2.73
84	SP	Dadeldhura	552P101	CF	453647	3241735	1334	50	300	53.5	29.7	3.0018	1826.777	0.072	46.78	2.41	2.56
85	SP	Dadeldhura	554P103	CF	453621	3241765	1346	45	0	20.2	10.3	0.1626	90.194	0.012	5.679	7.27	6.3
86	SP	Dadeldhura	555P104	CF	453316	3241818	1346	50	14	65	24.6	3.7688	2886.987	0.12	77.394	3.2	2.68
87	SP	Dadeldhura	556P105	CF	453338	3241824	1338	40	335	18	8.2	0.1134	70.411	0.009	4.255	8.31	6.04
88	SP	Doti	522P082	CF	474313	3214268	1145	65	93	45.6	29.9	2.1759	1201.707	0.051	26.28	2.32	2.19
89	SP	Doti	526P083	CF	474335	3214363	1221	60	70	56.9	29.5	3.6223	2293.386	0.091	60.682	2.52	2.65

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90	SP	Doti	541Pr093	GMF	493812	3233460	1041	10	45	29	22.3	0.7024	363.909	0.023	10.513	3.22	2.89
91	SP	Doti	543Pr095	GMF	493932	3233382	1010	45	55	61	32.65	4.3265	2853.475	0.101	57.31	2.33	2.01
92	SP	Doti	544Pr096	CF	503371	3237715	1582	35	270	71	28.3	5.187	3969.539	0.154	90.76	2.97	2.29
93	SP	Doti	545Pr097	CF	503391	3237746	1603	35	242	55.8	24.65	2.9073	1951.538	0.087	52.17	3	2.67
94	SP	Doti	546Pr098	CF	503382	3237744	1600	40	240	9.1	5.9	0.0227	9.81	0.003	1.044	11.44	10.64
95	SP	Doti	547Pr099	CF	503402	3237755	1560	35	70	33	18.2	0.7683	452.961	0.03	14.296	3.9	3.16
96	SP	Doti	557Pr106	CF	497060	3246881	1983	50	360	29.6	12.9	0.4592	238.071	0.025	11.476	5.52	4.82

e) *Schima wallichii*

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1	K	Bhojpur	127Sw015	CF	504317	3008154	1973	60	330	17.6	11.7	0.1395	87.456	0.014	5.665	9.81	6.48
2	K	Bhojpur	129Sw016	CF	504438	3008314	1994	45	270	27.1	15.3	0.3151	267.421	0.024	10.259	7.56	3.84
3	K	Dhankuta	063Sw007	CF	532983	2985760	1353	35	241	42	26.6	1.5965	1014.334	0.048	25.255	3	2.49
4	K	Dhankuta	065Sw008	CF	533008	2985762	1356	50	251	35.3	26.48	1.1251	702.56	0.038	19.483	3.37	2.77
5	K	Dhankuta	066Sw009	CF	533012	2985779	1402	52	250	14.5	15.2	0.111	55.517	0.008	3.762	7.58	6.78
6	K	Dhankuta	067Sw010	CF	533032	2985784	1375	60	235	9	7.5	0.0251	12.904	0.003	1.196	11.57	9.27
7	K	Ilam	046Sw003	CF	591542	2978481	1315	25	345	25.6	24.1	0.5403	276.105	0.025	11.037	4.55	4
8	K	Ilam	050Sw004	CF	591562	2978494	1315	63	310	42.5	24.4	1.3983	916.554	0.052	25.717	3.69	2.81
9	K	Ilam	052Sw005	CF	591540	2978521	1327	65	360	12.8	17.6	0.1188	60.997	0.006	2.389	4.95	3.92
10	K	Ilam	055Sw006	CF	591547	2978553	1324	60	340	51.9	29.4	2.5475	1552.577	0.098	48.585	3.84	3.13
11	K	Khotang	155Sw021	CF	466645	3016089	1460	25	257	49.4	18.5	1.4282	1332.994	0.081	43.223	5.68	3.24
12	K	Khotang	158Sw022	CF	472597	3013495	1927	35	95	35.2	14.6	0.6388	466.499	0.032	16.355	5.08	3.51
13	K	Sankhuwasabha	166Sw023	CF	527516	3016386	1360	38	198	14.4	12.4	0.0952	59.388	0.007	3.36	7.15	5.66
14	K	Sankhuwasabha	167Sw024	CF	527501	3016398	1354	45	220	21.8	10.65	0.1618	138.325	0.016	8.324	9.92	6.02
15	K	Sankhuwasabha	169Sw025	CF	527560	3016413	1361	27	233	30.4	17.7	0.5064	355.444	0.031	15.529	6.1	4.37
16	K	Terathum	097Sw011	CF	552644	3001467	1626	35	237	43.8	27	1.6015	1296.862	0.056	29.94	3.5	2.31
17	K	Terathum	098Sw012	CF	552695	3001413	1607	70	190	36	22.3	1.0584	677.907	0.038	18.339	3.62	2.71

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18	K	Terhathum	102Sw013	CF	552720	3001403	1603	70	190	27	18.3	0.5468	362.93	0.026	12.023	4.66	3.31
19	K	Terhathum	108Sw014	CF	552115	3002504	1748	60	30	15.7	12.2	0.1158	70.737	0.008	4.248	6.67	6.01
20	K	Udayepr	033Sw002	CF	459634	2974149	477	30	160	67.5	30.9	4.2843	2866.625	0.138	72.53	3.22	2.53
21	B	Dhading	304Sw034	CF	290329	3085388	519	35	100	39.9	21.7	1.1036	844.384	0.054	26.825	4.92	3.18
22	B	Dhading	305Sw035	CF	290332	3085402	549	42	95	19.7	15.3	0.2234	154.774	0.018	8.502	7.86	5.49
23	B	Dhading	326Sw040	CF	279334	3092280	711	60	235	29.6	16.8	0.466	318.079	0.031	16.24	6.63	5.11
24	B	Dhading	329Sw042	CF	302945	3095321	1462	32	205	54	22.5	1.9506	1258.687	0.103	52.858	5.28	4.2
25	B	Dhading	337Sw043	PF	299491	3095450	1394	45	90	5.5	6.1	0.0109	5.466	0.001	0.523	11.84	9.57
26	B	Dhading	341Sw044	PF	299413	3095529	1385	61	85	41	16.1	0.7232	517.395	0.058	29.437	8.08	5.69
27	B	Kavrepalanchok	202Sw027	CF	373283	3049533	1273	40	32	18.7	17.1	0.2605	155.209	0.013	5.966	4.87	3.84
28	B	Kavrepalanchok	250Sw028	CF	354618	3062617	1718	50	242	25.2	14.1	0.3172	149.255	0.024	7.481	7.46	5.01
29	B	Nuwakot	281Sw030	CF	326819	3079262	1898	52	75	22.5	12.5	0.2266	144.615	0.018	7.544	8.15	5.22
30	B	Nuwakot	319Sw038	CF	337475	3090300	954	52	100	17.4	15	0.1732	123.685	0.015	7.179	8.71	5.8
31	B	Sindhuli	141Sw017	CF	389239	3009739	592	76	89	32.2	23.55	0.8465	562.226	0.031	16.625	3.61	2.96
32	B	Sindhuli	144Sw018	CF	389264	3009780	570	57	149	29.8	23.55	0.6893	354.322	0.029	13.444	4.24	3.79
33	B	Sindhuli	150Sw019	CF	389206	3009772	580	55	92	45.2	32.8	2.3012	1525.434	0.061	28.893	2.66	1.89
34	G	Baglung	398Sw052	PF	740668	3128677	1780	32	40	15.5	9.7	0.0927	59.412	0.009	3.951	10.17	6.65
35	G	Baglung	399Sw053	PF	740671	3128678	1790	31	270	8.7	7.2	0.0244	13.073	0.003	1.201	11.26	9.18

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36	G	Gorkha	313Sw036	PF	271081	3088258	1100	15	192	53	15.7	1.0103	823.55	0.074	38.12	7.31	4.63
37	G	Gorkha	360Sw045	CF	251653	3101168	566	40	235	18	14.2	0.1387	84.777	0.011	5.402	8.15	6.37
38	G	Gorkha	362Sw046	Indeterminate	251660	3101212	560	19	240	27.4	16.3	0.2731	238.963	0.019	11.049	7.11	4.62
39	G	Gorkha	363Sw047	CF	251638	3101288	580	19	237	32.3	17.2	0.5004	293.988	0.041	18.788	8.27	6.39
40	G	Kaski	411Sw056	PA	788940	3129744	1170	18	63	41.2	26	1.5683	1025.574	0.07	38.019	4.48	3.71
41	G	Kaski	416Sw058	PF	788816	3129959	1070	17	79	57.6	24.7	2.2042	1982.126	0.1	59.763	4.53	3.02
42	G	Lamjung	378Sw050	CF	227880	3113293	470	13	219	8.7	5	0.0158	9.815	0.002	1.071	14.91	10.92
43	G	Myagdi	441Sw060	CF	748355	3142194	1850	47	38	45.5	27.6	1.6981	1224.946	0.074	39.347	4.37	3.21
44	G	Tanahu	316Sw037	CF	239569	3089172	652	55	30	51.8	19	1.3969	1242.755	0.081	42.778	5.83	3.44
45	G	Tanahu	365Sw048	CF	235696	3108993	847	70	163	61.4	20.45	1.773	2078.711	0.078	44.036	4.41	2.12
46	G	Tanahu	374Sw049	CF	235840	3109263	986	40	145	23.8	14.53	0.2349	206.76	0.016	7.728	6.68	3.74
47	L	Palpa	291Sw031	CF	750527	3082158	870	22.4	4	31	26.05	0.8843	426.275	0.027	12.522	3.1	2.94

f) Shorea robusta

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1	K	Jhapa	001Sr001	CF	592490	2949402	125	0	0	15.2	18.5	0.1541	92.442	0.007	3.617	4.68	3.91
2	K	Jhapa	002Sr002	CF	592422	2949506	125	0	0	46.1	30.3	2.2559	1944.214	0.062	41.111	2.75	2.11
3	K	Jhapa	003Sr003	CF	592434	2949453	126	0	0	37.5	28.5	1.3219	945.454	0.041	25.945	3.13	2.74
4	K	Jhapa	005Sr004	CF	592202	2949564	131	22	75	93.8	40.55	9.2969	8819.378	0.277	204.536	2.98	2.32
5	K	Jhapa	006Sr005	CF	592478	2949269	139	0	0	61.9	26.3	2.3104	2797.39	0.101	71.687	4.38	2.56
6	K	Morang	009Sr006	GMF	549985	2949973	174	0	0	10.2	12.6	0.047	23.597	0.003	1.126	5.42	4.77
7	K	Morang	011Sr007	GMF	549905	2949949	NA	0	0	51.3	33.9	2.9404	2464.527	0.081	54.127	2.74	2.2
8	K	Morang	014Sr008	GMF	549874	2950073	149	0	0	68.1	38.1	5.9435	5016.425	0.15	114.498	2.52	2.28
9	K	Morang	015Sr009	GMF	549985	2949973	174	0	0	23.5	24.58	0.5365	395.993	0.016	9.85	2.9	2.49
10	K	Morang	017Sr010	GMF	549871	2949983	162	0	0	45.6	35.7	2.5017	1889.78	0.062	39.547	2.5	2.09
11	K	Udayapur	031Sr011	CF	460206	2973567	418	37	128	70.4	31.85	5.0165	4908.512	0.135	96.93	2.68	1.97
12	K	Udayapur	034Sr012	CF	459679	2974156	515	15	85	69.2	30.7	4.7329	4797.037	0.159	106.983	3.36	2.23
13	K	Udayapur	036Sr013	CF	459788	2974373	438	17	45	57.6	31.3	3.5576	2753.058	0.094	59.289	2.63	2.15
14	K	Udayapur	037Sr014	CF	459708	2974189	498	45	130	27.3	21.1	0.5705	434.853	0.022	15.23	3.79	3.5
15	K	Udayapur	039Sr015	CF	459793	2974371	509	25	62	45.7	29.4	2.16	1989.429	0.064	46.085	2.97	2.32
16	K	Udayapur	041Sr017	CF	459667	2974142	510	25	152	35.6	19.7	0.8675	745.549	0.041	30.396	4.7	4.08
17	M	Dhanusa	073Sr021	CF	396436	2989039	317	5	215	38.4	22.3	1.0105	1016.05	0.051	34.594	5.02	3.4
18	M	Dhanusa	074Sr022	GMF	395858	2988938	294	50	280	41.3	20.8	0.8719	930.525	0.056	38.004	6.38	4.08

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19	M	Mahottari	069Sr018	GMF	380936	2985994	189	0	0	48.2	26.5	1.7869	1481.959	0.067	42.134	3.77	2.84
20	M	Mahottari	071Sr019	GMF	381075	2987524	193	0	0	65.6	30.8	4.5601	4064.861	0.14	95.307	3.06	2.34
21	M	Mahottari	072Sr020	GMF	380805	2986203	172	0	0	40.5	23.35	1.1445	1105.254	0.047	33.471	4.11	3.03
22	M	Rautahat	113Sr035	CFM	325320	3003001	144	0	0	25.7	22.35	0.5307	455.426	0.018	11.028	3.38	2.42
23	M	Rautahat	121Sr039	CFM	325225	3003174	125	0	0	95.1	34.5	10.6993	10231.4	0.289	194.288	2.7	1.9
24	M	Rautahat	122Sr040	CFM	325297	3003285	135	0	0	32.4	25.5	0.9074	829.007	0.029	18.665	3.18	2.25
25	M	Rautahat	123Sr041	CFM	325608	3003306	122	0	0	68.2	35.6	5.9674	5305.869	0.126	93.699	2.11	1.77
26	M	Rautahat	124Sr042	CFM	325634	3003410	121	0	0	56.8	31.5	3.5304	2893.824	0.098	63.249	2.77	2.19
27	M	Sarlahi	076Sr023	CFM	352495	2990430	118	0	0	60.5	29.2	3.4913	3149.836	0.107	69.909	3.07	2.22
28	M	Sarlahi	077Sr024	CFM	352399	2990408	107	0	0	46.9	30	2.1034	1842.928	0.075	49.32	3.58	2.68
29	M	Sarlahi	078Sr025	CFM	352643	2990442	110	0	0	16.8	18.6	0.2048	130.141	0.009	5.06	4.42	3.89
30	M	Sarlahi	089Sr031	CFM	352896	2990766	78	0	0	54.7	30.2	2.6826	2352.767	0.103	70.901	3.85	3.01
31	B	Chitwan	223Sr053	CF	266089	3060761	325	35	168	67.8	28.5	4.0715	4265.561	0.23	123.151	5.66	2.89
32	B	Chitwan	224Sr054	CF	266097	3060812	304	49	290	94.3	39.4	9.9444	10799.89	0.259	199.676	2.61	1.85
33	B	Chitwan	226Sr056	CF	266128	3060782	343	45	152	53.8	24.4	2.4049	2228.87	0.081	60.664	3.36	2.72
34	B	Chitwan	228Sr057	CF	266153	3060820	319	30	275	21.9	20.6	0.3871	244.374	0.013	8.024	3.42	3.28
35	B	Chitwan	255Sr070	CF	262214	3064570	656	30	348	55.8	26.4	3.3601	2616.555	0.09	60.815	2.69	2.32
36	B	Chitwan	256Sr071	CF	262221	3064712	639	25	320	46.5	28.7	2.165	2196.519	0.063	42.921	2.9	1.95
37	B	Dhading	302Sr084	CF	290304	3085378	528	40	105	29.5	25.4	0.7163	610.03	0.024	14.628	3.33	2.4

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38	B	Dhading	303Sr085	CF	290310	3085381	530	40	100	46	29.6	1.7424	1470.506	0.062	40.13	3.59	2.73
39	B	Dhading	306Sr086	CF	290324	3085434	488	68	92	36.8	27.2	1.4025	1100.116	0.047	28.95	3.37	2.63
40	B	Kavrepalanchok	246Sr069	CF	362523	3062327	1038	44	88	7.9	7.1	0.019	11.825	0.002	0.926	11.19	7.83
41	B	Makwanpur	179Sr043	CF	317814	3031569	614	40	192	66.2	25.6	3.9255	3466.753	0.163	103.062	4.16	2.97
42	B	Makwanpur	183Sr044	CF	317847	3031582	642	55	210	34.8	21.75	0.8932	832.525	0.037	24.627	4.16	2.96
43	B	Makwanpur	186Sr045	CF	235665	3097392	513	40	110	32.6	24.4	0.8479	669.547	0.033	21.275	3.85	3.18
44	B	Makwanpur	187Sr046	CF	303037	3035863	411	42	181	80.3	42	8.3603	7386.317	0.183	120.893	2.19	1.64
45	B	Makwanpur	189Sr047	CF	317830	3031369	621	55	142	44.2	19.5	1.0287	723.293	0.055	33.095	5.39	4.58
46	B	Sindhuli	083Sr027	CF	406070	2990646	316	0	0	32	24.85	0.8199	645.123	0.026	16.225	3.23	2.52
47	B	Sindhuli	084Sr028	CF	406074	2990648	313	0	0	53.8	29	2.8004	2490.94	0.094	60.616	3.34	2.43
48	B	Sindhuli	086Sr029	CF	406061	2990683	291	0	0	67.5	28.85	5.0687	4214.602	0.142	106.176	2.8	2.52
49	B	Sindhuli	087Sr030	CF	405942	2990548	311	41	0	49.7	29.1	2.582	2091.553	0.095	65.526	3.69	3.13
50	B	Sindhuli	091Sr032	CF	406164	2990743	320	0	0	26.4	20.2	0.5254	452.052	0.02	12.315	3.75	2.72
51	G	Lamjung	383Sr103	CF	227429	3114050	480	43	280	68.7	33.7	4.8696	4472.52	0.141	96.843	2.89	2.17
52	G	Nawalparasi (E)	214Sr050	CF	790319	3057905	191	0	0	61.6	28.6	3.54	3201.256	0.111	74.859	3.14	2.34
53	G	Nawalparasi (E)	215Sr051	CF	790272	3057889	182	5	65	56	28.2	3.3987	2769.065	0.085	55.572	2.5	2.01
54	G	Nawalparasi (E)	216Sr052	CF	790319	3057905	184	15	216	48.9	26.9	2.3007	2112.66	0.077	55.418	3.34	2.62
55	G	Nawalparasi (E)	231Sr058	BZCF	218442	3061726	187	0	0	59.9	26.5	3.7046	2894.063	0.1	66.905	2.69	2.31
56	G	Nawalparasi (E)	232Sr059	BZCF	218457	3061748	206	0	0	102.4	34.9	10.6158	10497.93	0.393	298.644	3.7	2.84

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57	G	Nawalparasi (E)	233S060	BZCF	218431	3061759	187	0	0	35.5	23.9	1.0435	851.276	0.041	23.448	3.96	2.75
58	G	Nawalparasi (E)	234S061	BZCF	218431	3061759	187	0	0	31.3	18.3	0.5805	583.879	0.028	17.847	4.89	3.06
59	G	Nawalparasi (E)	235S062	GMF	794151	3061765	309	26	5	41.8	24.9	1.8463	1371.941	0.051	34.53	2.77	2.52
60	G	Nawalparasi (E)	236S063	BZCF	218514	3061771	190	0	0	12.6	13.2	0.0745	53.878	0.005	2.338	6.2	4.34
61	G	Nawalparasi (E)	238S065	BZCF	218115	3061794	190	0	0	80.7	39.9	8.8183	7749.053	0.246	146.598	2.79	1.89
62	G	Nawalparasi (E)	239S066	BZCF	218579	3061794	190	0	0	47.2	31.7	2.4093	2502.083	0.072	56.456	3	2.26
63	G	Nawalparasi (E)	243S068	GMF	794485	3062042	222	27	25	72.5	32.8	7.7247	6901.76	0.188	147.128	2.44	2.13
64	G	Tanahu	315S087	CF	239568	3089107	689	60	35	48.8	24.55	1.7322	1599.797	0.061	41.501	3.5	2.59
65	G	Tanahu	317S088	RF	239369	3089162	741	42	340	53.5	22.25	1.5589	2213.458	0.105	67.08	6.76	3.03
66	G	Tanahu	346S090	CF	235034	3097399	511	80	172	7.4	9	0.0202	11.754	0.001	0.74	6.74	6.3
67	G	Tanahu	366S094	CF	244099	3108994	760	80	60	55.7	22.57	2.0165	1772.293	0.08	53.868	3.97	3.04
68	G	Tanahu	367S095	CF	244047	3109025	765	30	215	44	18.6	1.0281	929.852	0.067	44.55	6.54	4.79
69	G	Tanahu	369S096	CF	244012	3109074	779	30	250	12.2	14.5	0.0902	68.638	0.005	3.221	5.19	4.69
70	G	Tanahu	370S097	CF	244040	3109075	757	40	125	68.5	25.8	2.7782	2892.063	0.127	87.457	4.56	3.02
71	G	Tanahu	376S098	CF	210970	3109949	690	60	260	52.3	23	2.0145	2329.085	0.073	50.437	3.6	2.17
72	L	Arghakhanchi	274S077	CF	703365	3070831	180	5	180	23.2	16.4	0.3618	262.33	0.015	9.776	4.17	3.73
73	L	Arghakhanchi	275S078	CF	703121	3070859	183	10	180	41.3	28.5	1.7935	1445.624	0.054	41.958	3.01	2.9
74	L	Arghakhanchi	280S079	CF	702674	3071128	180	0	0	10.7	12.4	0.0584	36.205	0.004	1.984	6.01	5.48
75	L	Arghakhanchi	289S081	CF	697880	3079934	1140	45	161	38	20.8	0.8714	669.598	0.043	27.911	4.88	4.17

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76	L	Arghakhanchi	286S080	CF	697659	3079729	1100	32	132	48	18.6	1.2081	1365.648	0.081	56.986	6.72	4.17
77	L	Arghakhanchi	300S083	GMF	688813	3083306	605	40	345	51.9	18.4	1.1789	1657.465	0.071	46.077	6.05	2.78
78	L	Bardiya	424Sr104	PA	547692	3130951	173	0	0	58.5	30.4	3.1156	2399.519	0.102	66.74	3.27	2.78
79	L	Bardiya	430Sr105	BZCF	547797	3131041	206	0	0	79.5	30.5	5.5405	5264.61	0.226	114.997	4.08	2.18
80	L	Dang	297Sr082	CF	669739	3083056	300	0	0	14.7	13.9	0.1181	72.314	0.006	3.718	5.43	5.14
81	L	Dang	379Sr099	CF	617060	3113577	630	0	0	72.6	24.6	4.1255	4051.328	0.167	113.745	4.04	2.81
82	L	Dang	380Sr100	CF	617008	3113622	637	0	0	59.8	23.9	2.4757	2872.253	0.109	72.539	4.4	2.53
83	L	Dang	381Sr101	CF	617135	3113685	637	0	0	57.4	23.9	2.5463	2435.45	0.12	78.417	4.73	3.22
84	L	Dang	382Sr102	CF	617124	3113943	638	0	0	35.6	25.9	1.1208	902.564	0.037	24.114	3.28	2.67
85	L	Kapilbastu	262Sr072	CF	714300	3067921	174	0	0	58.9	33.7	4.0292	3517.243	0.12	78.589	2.97	2.23
86	L	Kapilbastu	264Sr073	CF	715033	3069670	176	0	0	35.2	20.5	0.9287	644.766	0.036	21.215	3.86	3.29
87	L	Kapilbastu	267Sr074	CF	714233	3068133	159	0	0	54.5	30.5	3.0478	2404.623	0.1	72.48	3.27	3.01
88	L	Kapilbastu	268Sr075	CF	714204	3068055	149	2	0	12.6	12.5	0.0821	50.088	0.005	2.696	5.71	5.38
89	L	Kapilbastu	269Sr076	CF	714298	3068956	167	0	0	75	34.7	6.6165	5786.359	0.226	139.451	3.42	2.41
90	L	Nawalparasi (W)	204Sr048	CF	770248	3057197	155	1	1	34.8	21.3	0.7697	613.635	0.033	20.663	4.3	3.37
91	L	Nawalparasi (W)	209Sr049	CF	770201	3057292	187	0	0	25.3	20.3	0.4967	420.71	0.019	13.157	3.88	3.13
92	L	Pyuthan	347Sr091	CF	673045	3099048	915	38	171	17.4	13	0.1617	114.654	0.01	5.909	6.49	5.15
93	L	Pyuthan	348Sr092	CF	673050	3099054	915	38	171	9.1	9.8	0.0369	20.096	0.003	1.346	6.91	6.7
94	L	Pyuthan	351Sr093	CF	673156	3099118	927	26	150	23.6	18.5	0.3208	237.514	0.015	8.905	4.66	3.75

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95	KR	Dailekh	499Sr119	CF	560058	3183042	686	35	40	34.5	22.7	0.8478	694.106	0.032	20.29	3.72	2.92
96	KR	Dailekh	505Sr123	CF	556108	3184431	683	30	240	41.1	28.2	1.6746	1316.735	0.046	31.415	2.76	2.39
97	KR	Dailekh	507Sr124	CF	556042	3184503	645	35	278	27.4	23.9	0.6156	567.662	0.026	19.983	4.24	3.52
98	KR	Dailekh	517Sr127	CF	566747	3192106	777	5	216	8.5	8.8	0.0265	14.83	0.002	1.158	8.89	7.81
99	KR	Jajarkot	465Sr110	CF	612174	3170029	1229	35	105	6.7	4.9	0.0113	5.571	0.001	0.574	10.81	10.31
100	KR	Jajarkot	474Sr112	CF	612181	3170044	1232	35	105	32.7	12.3	0.2592	345.614	0.035	22.248	13.47	6.44
101	KR	Rukum (W)	471Sr111	CF	619713	3169793	887	30	210	21.3	19.9	0.355	209.938	0.014	7.24	3.89	3.45
102	KR	Rukum (W)	475Sr113	CF	619714	3169826	889	45	210	16.5	14.9	0.1868	102.318	0.007	3.949	3.88	3.86
103	KR	Surkhet	448Sr106	CF	553415	3163981	445	0	0	45.1	26.5	1.7868	1526.242	0.064	41.145	3.59	2.7
104	KR	Surkhet	449Sr107	CF	553484	3164028	450	0	0	62.4	28.2	3.949	2754.077	0.106	64.214	2.69	2.33
105	KR	Surkhet	451Sr108	CF	553352	3164150	446	0	0	39.2	20.2	1.2628	982.083	0.042	25.537	3.34	2.6
106	KR	Surkhet	455Sr109	CF	551055	3168525	682	25	27	95.6	35.1	10.5809	8380.86	0.333	205.272	3.14	2.45
107	KR	Surkhet	532Sr135	CF	550866	3168472	726	28	60	25	19.6	0.4606	309.855	0.018	10.171	3.81	3.28
108	KR	Surkhet	533Sr136	CF	550912	3168503	523	24	14	33.4	28.9	1.0687	769.939	0.033	20.451	3.07	2.66
109	SP	Dadeldhura	523Sr129	CF	451119	3214269	1135	45	105	67	24.3	2.8909	3320.541	0.113	73.65	3.93	2.22
110	SP	Dadeldhura	524Sr130	CF	451038	3214180	1138	30	150	51	21.7	1.2497	1401.892	0.073	49.124	5.83	3.5
111	SP	Doti	521Sr128	CF	474313	3214253	11	85	120	8.5	6.7	0.0225	15.842	0.002	1.474	10.47	9.3
112	SP	Doti	525Sr131	CF	474331	3214297	1210	85	335	46.9	22.5	1.6345	1560.932	0.062	38.529	3.76	2.47
113	SP	Doti	527Sr132	CF	478543	3214216	1306	45	260	16.6	12.3	0.1426	116.574	0.011	5.733	7.57	4.92

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114	SP	Doti	528Sr133	CF	478522	3214209	1285	45	0	34.1	15.7	0.6447	707.844	0.039	25.913	6.08	3.66
115	SP	Kailali	477Sr114	CF	470483	3173330	190	0	0	30.4	24.4	0.7982	517.543	0.026	17.743	3.25	3.43
116	SP	Kailali	483Sr115	CF	470600	3173923	189	0	0	69.9	24.6	4.6778	3615.331	0.166	115.885	3.55	3.21
117	SP	Kailali	485Sr116	CF	481654	3177937	150	0	0	23.3	19.7	0.352	198.525	0.016	8.871	4.63	4.47
118	SP	Kailali	487Sr117	CF	481602	3177960	200	0	0	58.8	25.1	2.6336	3343.163	0.115	75.723	4.36	2.26
119	SP	Kailali	500Sr120	CF	465319	3184165	185	3	0	47	31.7	2.3229	1746.631	0.069	48.513	2.96	2.78
120	SP	Kailali	502Sr121	CF	464946	3184390	189	0	0	18.6	12.8	0.1491	92.309	0.011	6.027	7.58	6.53
121	SP	Kailali	504Sr122	CF	464773	3184782	185	0	0	87.6	34.9	8.5026	7616.877	0.302	227.653	3.56	2.99
122	SP	Kailali	510Sr126	CF	464781	3184748	184	0	0	96	40.3	12.1019	9553.18	0.375	256.432	3.1	2.68

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1	K	Jhapa	004Ta001	CF	592258	2949535	129	30	95	64.9	32.5	4.0536	3236.281	0.148	109.34	3.66	3.38
2	K	Morang	007Ta002	GMF	549899	2949930	161	0	0	29.5	22.3	0.6273	439.551	0.028	17.252	4.47	3.92
3	K	Morang	010Ta003	GMF	550018	2949945	174	0	0	46.1	30.6	2.0868	1776.822	0.068	45.579	3.26	2.57
4	K	Morang	012Ta004	GMF	549981	2949952	172	0	0	67.2	33.8	3.9199	3394.358	0.139	86.605	3.55	2.55
5	K	Morang	022Ta006	GMF	549920	2950103	149	0	0	39.9	26.3	1.6311	1448.805	0.053	36.223	3.25	2.5
6	K	Sunsari	025Ta007	CF	533086	2959599	215	0	0	77.8	31.8	6.3598	5887.636	0.224	151.825	3.52	2.58
7	K	Sunsari	030Ta008	CF	461682	2973850	188	0	0	97.2	34.9	8.6604	7031.307	0.27	189.177	3.12	2.69
8	K	Udayapur	035Ta009	CF	459646	2974251	496	35	182	44.5	32.4	1.9789	1712.456	0.054	38.326	2.72	2.24
9	K	Udayapur	042Ta010	CF	459643	2974220	491	65	80	51.5	32.9	3.4001	2756.971	0.085	64.219	2.49	2.33
10	M	Sarlahi	093Ta013	CF	352399	2990408	140	0	0	26	20	0.4777	438.811	0.022	14.998	4.68	3.42
11	M	Sarlahi	094Ta014	CF	376582	2998078	398	78	209	48.3	25	2.083	2157.982	0.07	55.459	3.35	2.57
12	M	Sarlahi	096Ta015	CF	370394	2993113	149	0	0	50.7	26.1	1.8777	2013.959	0.089	66.512	4.75	3.3
13	B	Chitwan	229Ta031	CF	266246	3060871	330	52	120	20	16.5	0.2523	212.309	0.014	8.803	5.74	4.15
14	B	Chitwan	254Ta033	CF	262237	3064521	672	12	310	23.4	14.5	0.339	231.561	0.016	10.253	4.77	4.43
15	B	Makwanpur	176Ta017	CF	317191	3025660	515	35	264	103.2	34.8	10.688	8972.825	0.35	238.519	3.27	2.66

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16	B	Makwanpur	188Ta020	CF	317805	3031574	588	15	205	49.7	23.4	1.6689	1473.619	0.065	44.382	3.89	3.01
17	B	Makwanpur	190Ta021	CF	316763	3025923	439	55	170	77.4	34.9	6.611	6258.902	0.165	123.906	2.5	1.98
18	G	Nawalparasi (W)	217Ta025	CF	790392	3057921	197	0	0	39.7	19.3	1.0851	1313.641	0.054	39.753	4.94	3.03
19	G	Nawalparasi (W)	218Ta026	CF	790362	3057933	194	15	273	32	18.9	0.6642	577.4	0.032	20.779	4.86	3.6
20	G	Nawalparasi (W)	219Ta027	CF	790443	3057961	192	0	0	42.5	29.4	1.8231	1492.993	0.048	32.926	2.62	2.21
21	G	Nawalparasi (W)	220Ta028	CF	790069	3057967	205	0	0	51.1	32.3	2.6366	2588.603	0.077	54.381	2.93	2.1
22	G	Nawalparasi (W)	221Ta029	CF	790275	3057979	185	29	121	13.2	12.5	0.0825	56.377	0.005	2.475	5.92	4.39
23	G	Nawalparasi (W)	222Ta030	CF	790273	3057982	192	15	37	24.9	18.6	0.3608	362.973	0.021	14.374	5.84	3.96
24	G	Nawalparasi (W)	242Ta032	GMF	794145	3061934	198	25	83	25	21.1	0.4796	523.444	0.02	13.589	4.16	2.6
25	L	Arghakhanchi	278Ta043	CF	702751	3071046	180	0	0	47.6	30.8	2.0944	1977.478	0.073	62.671	3.48	3.17
26	L	Arghakhanchi	307Ta047	GMF	693674	3087674	847	38	181	6.3	4.8	0.0095	7.046	0.001	0.894	15.09	12.68
27	L	Arghakhanchi	277Ta042	CF	702846	3070974	182	5	180	33.9	26.5	0.938	783.41	0.039	25.187	4.12	3.21
28	L	Arghakhanchi	294Ta045	GMF	681599	3082395	402	0	0	93.5	32.5	7.2537	6610.842	0.268	182.481	3.7	2.76
29	L	Arghakhanchi	309Ta048	GMF	693773	3087699	845	43	171	11.1	8.9	0.0455	38.904	0.004	2.882	9.86	7.41
30	L	Bardiya	426Ta051	BZCF	547803	3131000	135	0	0	63.5	32.9	4.3733	3833.851	0.142	92.209	3.24	2.41
31	L	Bardiya	427Ta052	BZCF	547641	3131004	150	0	0	39	26.3	1.3226	1173.347	0.06	43.146	4.54	3.68

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32	L	Bardiya	432Ta053	BZCF	548118	3132123	162	0	0	42.8	23.9	1.132	899.214	0.05	29.395	4.4	3.27
33	L	Dang	272Ta039	GMF	653832	3075565	368	35	25	56.9	28.9	3.2949	2498.701	0.117	71.69	3.55	2.87
34	L	Dang	273Ta040	GMF	653796	3070610	355	20	335	32.1	21.6	0.7959	758.648	0.03	22.434	3.79	2.96
35	L	Kapilbastu	258Ta035	CF	685952	3067285	174	0	0	51.5	29.9	2.5464	2403.232	0.08	67.878	3.15	2.82
36	L	Kapilbastu	259Ta036	GMF	685866	3067307	125	0	0	14.1	15.9	0.1256	82.968	0.007	4.358	5.49	5.25
37	L	Kapilbastu	260Ta037	CF	685812	3067321	141	0	0	32.5	22.3	0.8448	757.725	0.037	26.989	4.37	3.56
38	L	Kapilbastu	261Ta038	CF	685784	3067365	177	0	0	19.8	21.9	0.3278	243.313	0.013	8.861	3.94	3.64
39	L	Navalparasi (W)	205Ta022	CF	770230	3057197	160	0	0	42.5	27.15	1.3935	1237.544	0.054	39.141	3.9	3.16
40	L	Navalparasi (W)	208Ta023	CF	770233	3057223	149	0	0	43.3	25	1.609	1461.306	0.054	40.933	3.37	2.8
41	L	Pyuthan	349Ta049	CF	673145	3099054	911	41	155	18.4	15.2	0.1911	161.817	0.009	7.097	4.93	4.39
42	L	Pyuthan	350Ta050	CF	673154	3099055	912	40	105	8.9	8.5	0.0235	14.718	0.003	1.438	11.48	9.77
43	KR	Dailekh	506Ta069	CF	556063	3184437	660	30	185	42.4	28.8	1.7422	1724.837	0.053	39.093	3.05	2.27
44	KR	Surkhet	450Ta054	CF	553063	3163920	440	0	0	65.7	38.4	4.5363	3736.219	0.142	95.837	3.12	2.57
45	KR	Surkhet	452Ta055	CF	553709	3164188	451	0	0	16.1	16.08	0.1881	112.373	0.012	6.647	6.4	5.92
46	KR	Surkhet	453Ta056	CF	551065	3168456	706	31	43	52	24	1.8857	1675.663	0.095	75.363	5.04	4.5
47	KR	Surkhet	454Ta057	CF	550957	3168518	715	30	2	5.4	5.9	0.0081	4.381	0.001	0.525	14.66	11.98

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48	SP	Dadeldhura	520Ta074	CF	450406	3213929	993	45	240	71	32.4	5.3336	5108.127	0.147	110.343	2.75	2.16
49	SP	Kailali	478Ta058	CF	470519	3173366	138	0	0	23.9	15.9	0.3266	345.234	0.019	10.6	5.7	3.07
50	SP	Kailali	479Ta059	CF	470586	3173380	198	0	0	19.3	15.1	0.2043	174.643	0.012	8.907	6.05	5.1
51	SP	Kailali	480Ta060	CF	470443	3173389	190	0	0	49.9	22.8	1.8746	2056.291	0.085	60.215	4.51	2.93
52	SP	Kailali	481Ta061	CF	470564	3173522	190	0	0	8.9	8.3	0.031	17.179	0.003	1.257	8.87	7.31
53	SP	Kailali	482Ta062	CF	470402	3173522	190	0	0	37	21.6	0.8468	860.81	0.04	26.982	4.75	3.13
54	SP	Kailali	484Ta063	CF	470677	3174149	170	0	0	68	29	4.1555	3695.437	0.162	124.834	3.91	3.38
55	SP	Kailali	488Ta064	CF	481670	3178018	180	0	0	9.2	9.5	0.0383	22.351	0.003	1.498	8.14	6.7
56	SP	Kailali	489Ta065	CF	481676	3178018	180	0	0	19.4	16.7	0.2557	152.775	0.012	7.454	4.87	4.88
57	SP	Kailali	490Ta066	CF	481678	3178026	198.6	0	0	21.8	17.1	0.2926	233.083	0.014	8.155	4.83	3.5
58	SP	Kanchanpur	513Ta070	PA	430040	3190499	202	0	0	21.1	17.8	0.2955	177.949	0.014	6.774	4.79	3.81
59	SP	Kanchanpur	514Ta071	PA	430044	3190518	203	0	0	45.2	32.05	2.044	1764.895	0.062	41.332	3.03	2.34
60	SP	Kanchanpur	515Ta072	PA	430024	3190521	201	0	0	35.4	21.8	0.8311	636.664	0.042	25.433	5.05	3.99
61	SP	Kanchanpur	516Ta073	PA	430028	3190547	203	0	0	67.3	34.85	4.1643	4574.809	0.15	92.038	3.59	2.01

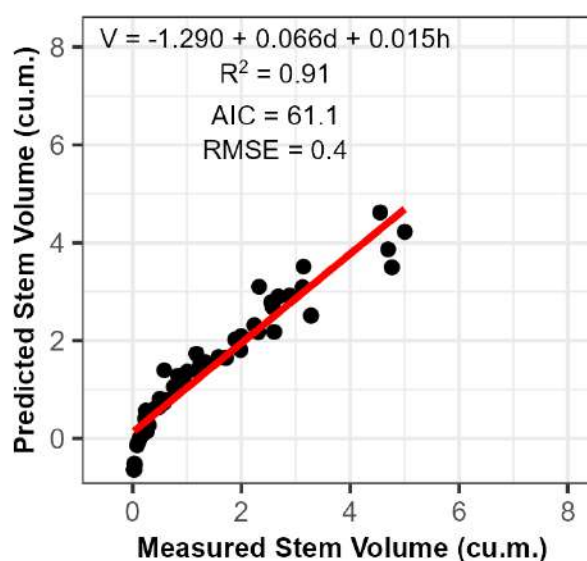
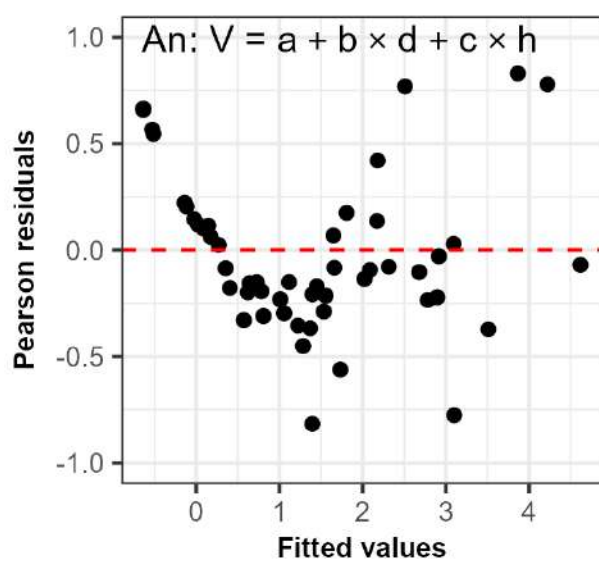
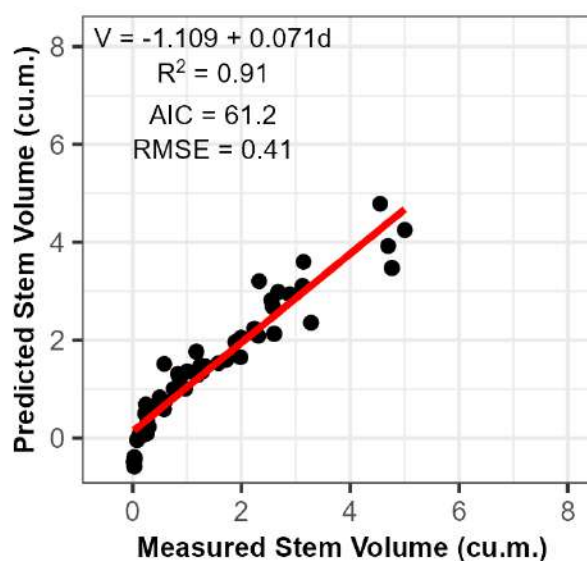
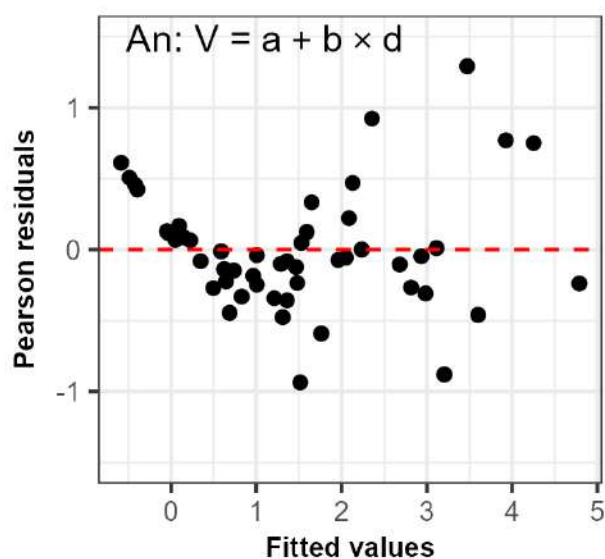
Note: Provinces (K: Koshi, M: Madhesh, B: Bagmati, G: Gandaki, L: Lumbini, KR: Karnali, SP: Sudurpaschim), Management Type (BZCF: Buffer Zone Community Forest, CF: Community Forest, CFM: Collaborative Forest, GMF: Government Managed Forest, LHF: Leasehold Forest, PA: Protected Area, PF: Private Forest, RF: Religious Forest)

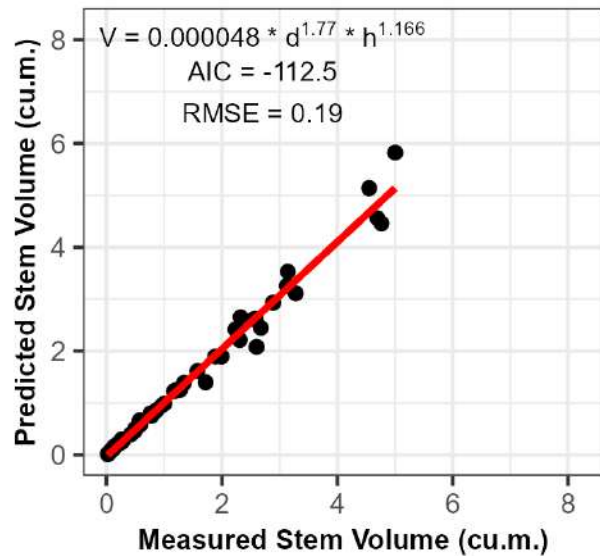
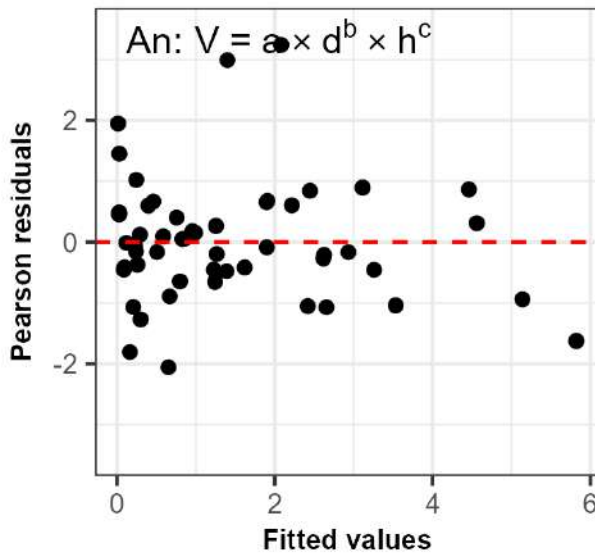
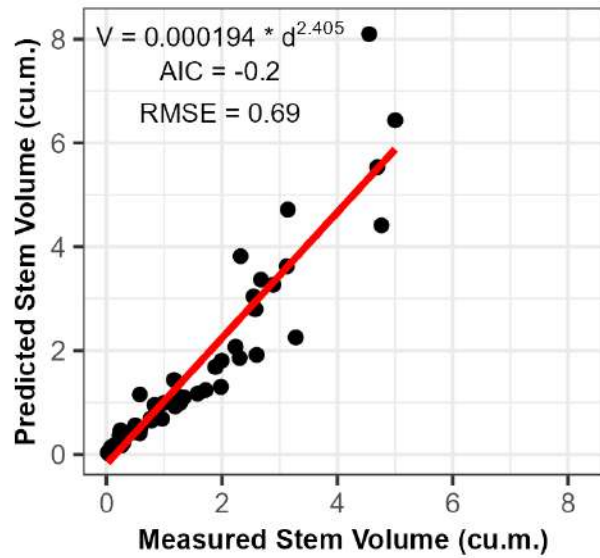
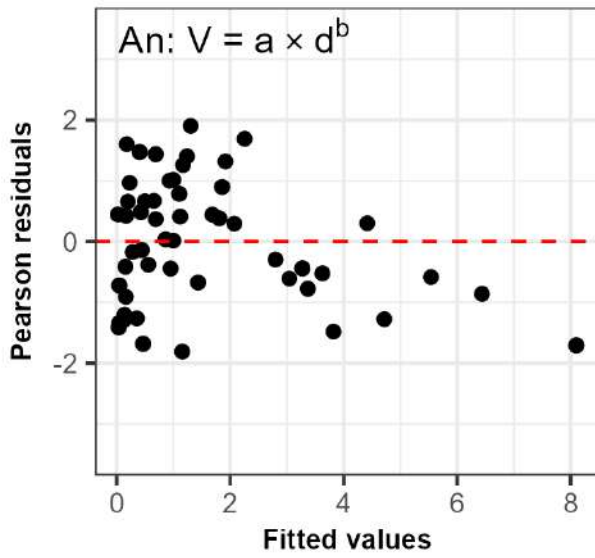
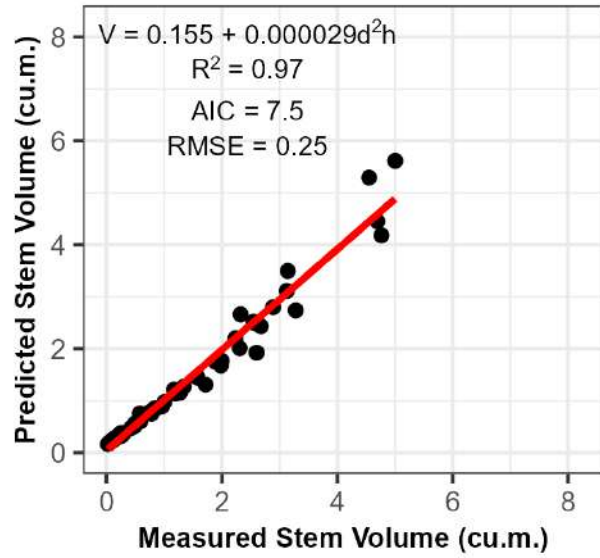
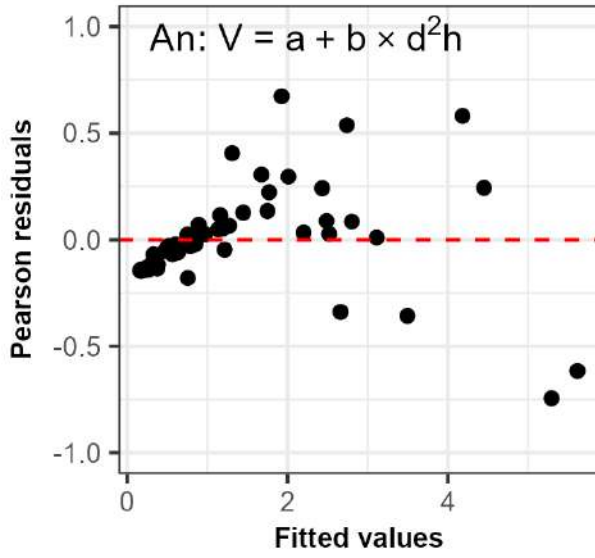
Annex III

Total Stem Volume Models

Table A3.1: Summary of performance metrics for candidate models of *Alnus nepalensis*.
(All displayed parameters are significant at 5%)

Model	Equation	n	a	b	c	AIC	R ²	RMSE	MB
M1	$V = a + b * d$	52	-1.108689	0.070707	-	61.17	0.91	0.42	-
M2	$V = a + b * d + c * h$	52	-1.289772	0.066339	0.015004	61.12	0.92	0.41	-
M3	$V = a + b * d^2h$	52	0.154834	0.000029	-	7.49	0.97	0.25	-
M4	$V = a * d^b$	52	0.000194	2.404857	-	-0.2	-	0.69	-0.12
M5	$V = a * d^b * h^c$	52	0.000048	1.769901	1.165658	-112.5	-	0.19	-0.02
M6	$V = a * (d^2h)^b$	52	0.000062	0.946754	-	-110.1	-	0.28	-0.06





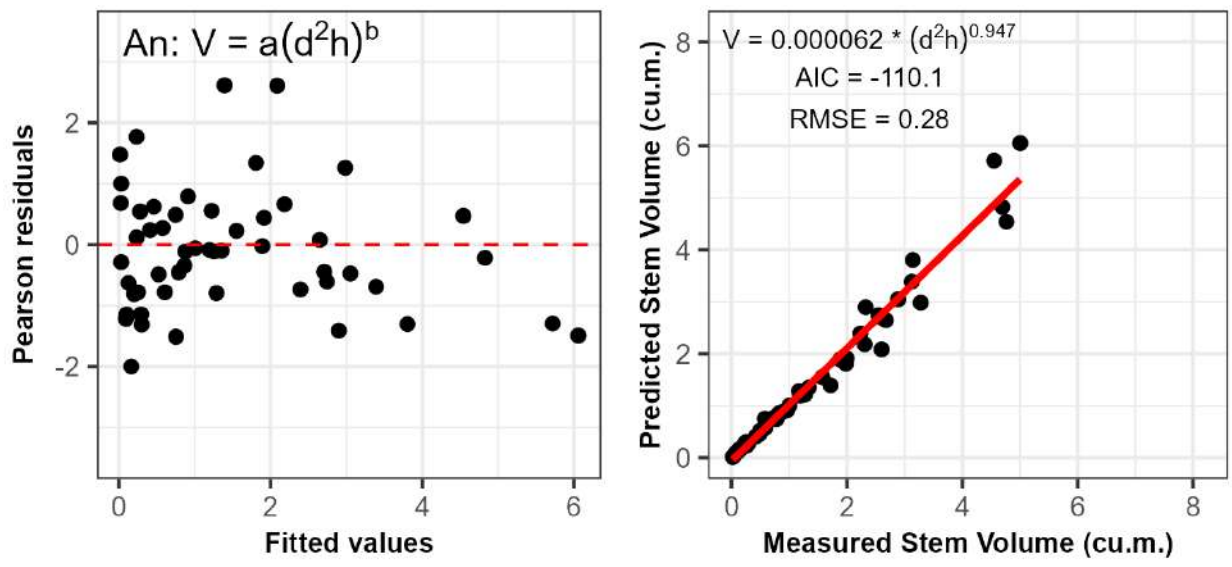
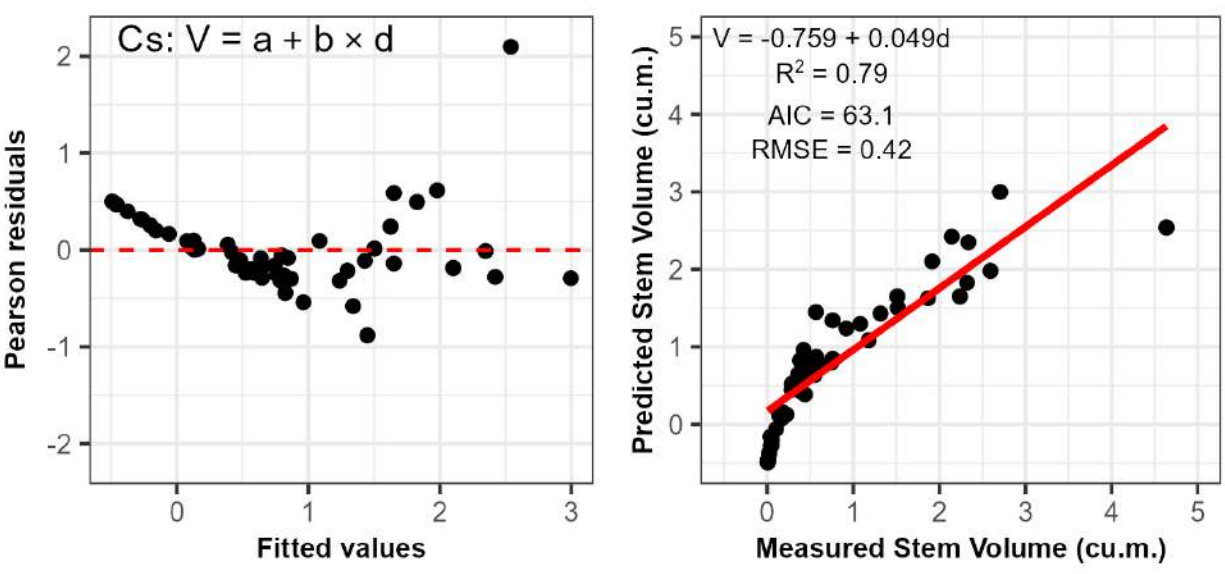
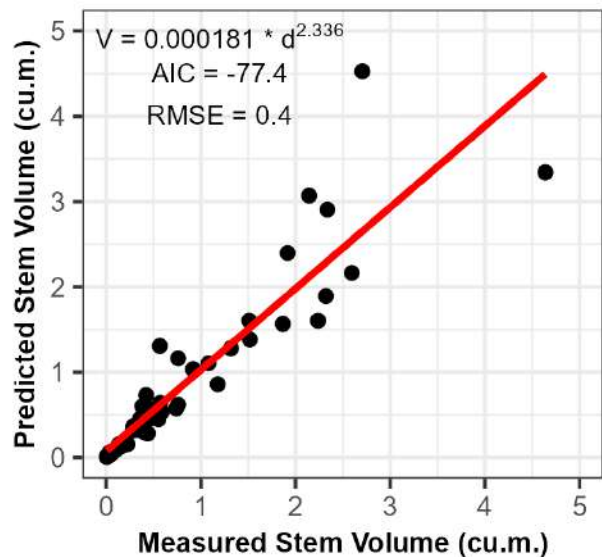
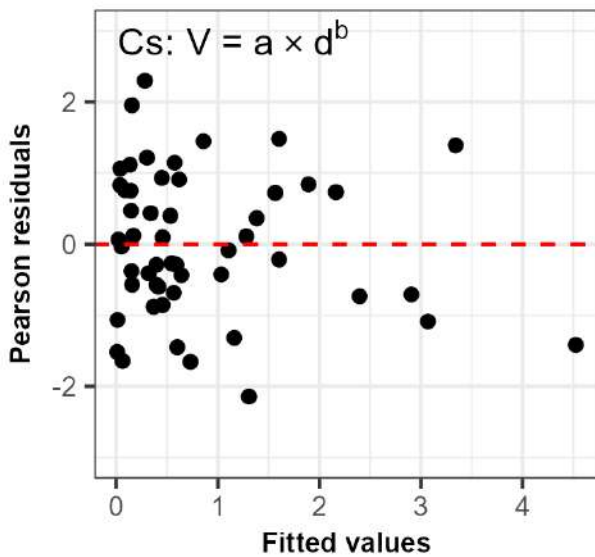
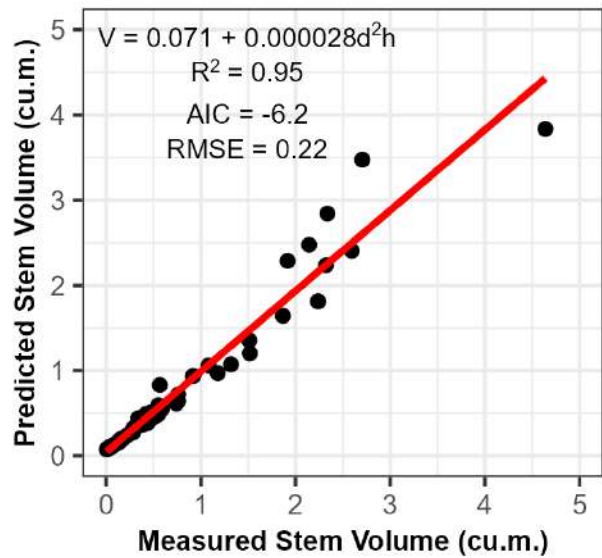
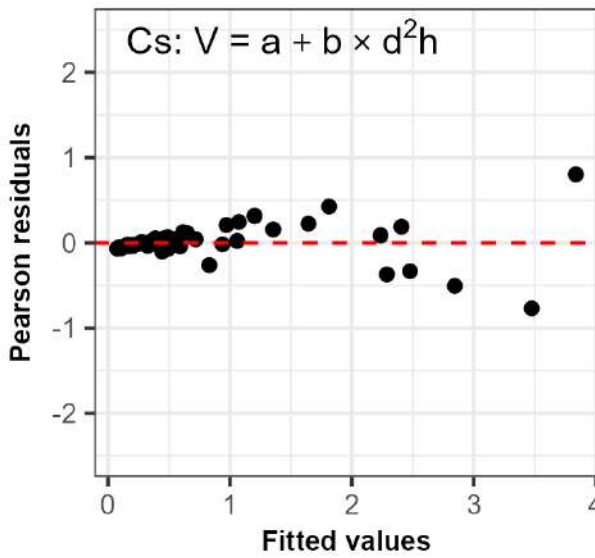
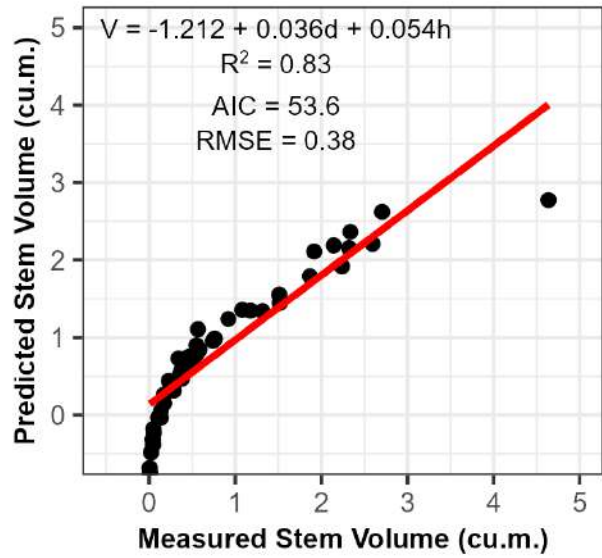
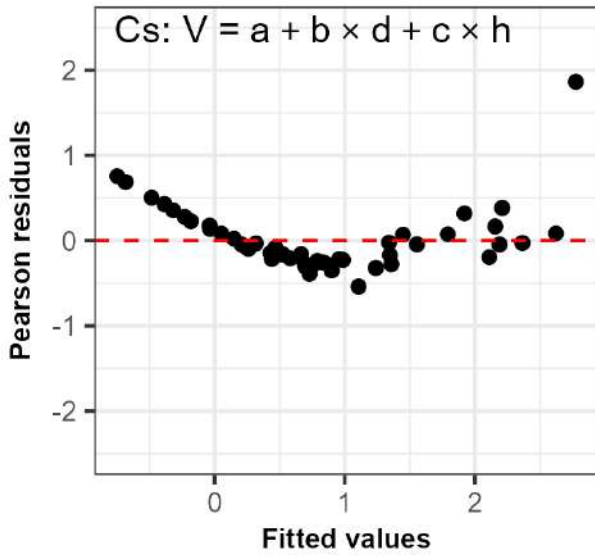


Figure A3.1: Left figures show the Pearsons residuals versus fitted values, indicating the distribution of errors, while right figures show the relationship between predicted versus the measured total stem volume of *Alnus nepalensis*. Models' performance is summarized by the equations, AIC, and RMSE for each model in the right figures. For tree code (An, Cs, Lp, Sw, Pr, Sr, Ta) refer Table 1.

Table A3.2: Summary of performance metrics for candidate models of *Castanopsis* spp. (All displayed parameters are significant at 5%).

Model	Equation	n	a	b	c	AIC	R ²	RMSE	MB
M1	$V = a + b * d$	52	-0.758527	0.049161	-	63.07	0.79	0.42	-
M2	$V = a + b * d + c * h$	52	-1.211528	0.035580	0.054365	53.57	0.83	0.38	-
M3	$V = a + b * d^2h$	52	0.070531	0.000028	-	-6.19	0.95	0.22	-
M4	$V = a * d^b$	52	0.000181	2.336033	-	-77.40	-	0.40	-0.04
M5	$V = a * d^b * h^c$	52	0.000055	1.800815	1.073780	-143.70	-	0.20	-0.02
M6	$V = a * (d^2h)^b$	52	0.000064	0.936534	-	-149.50	-	0.22	-0.03





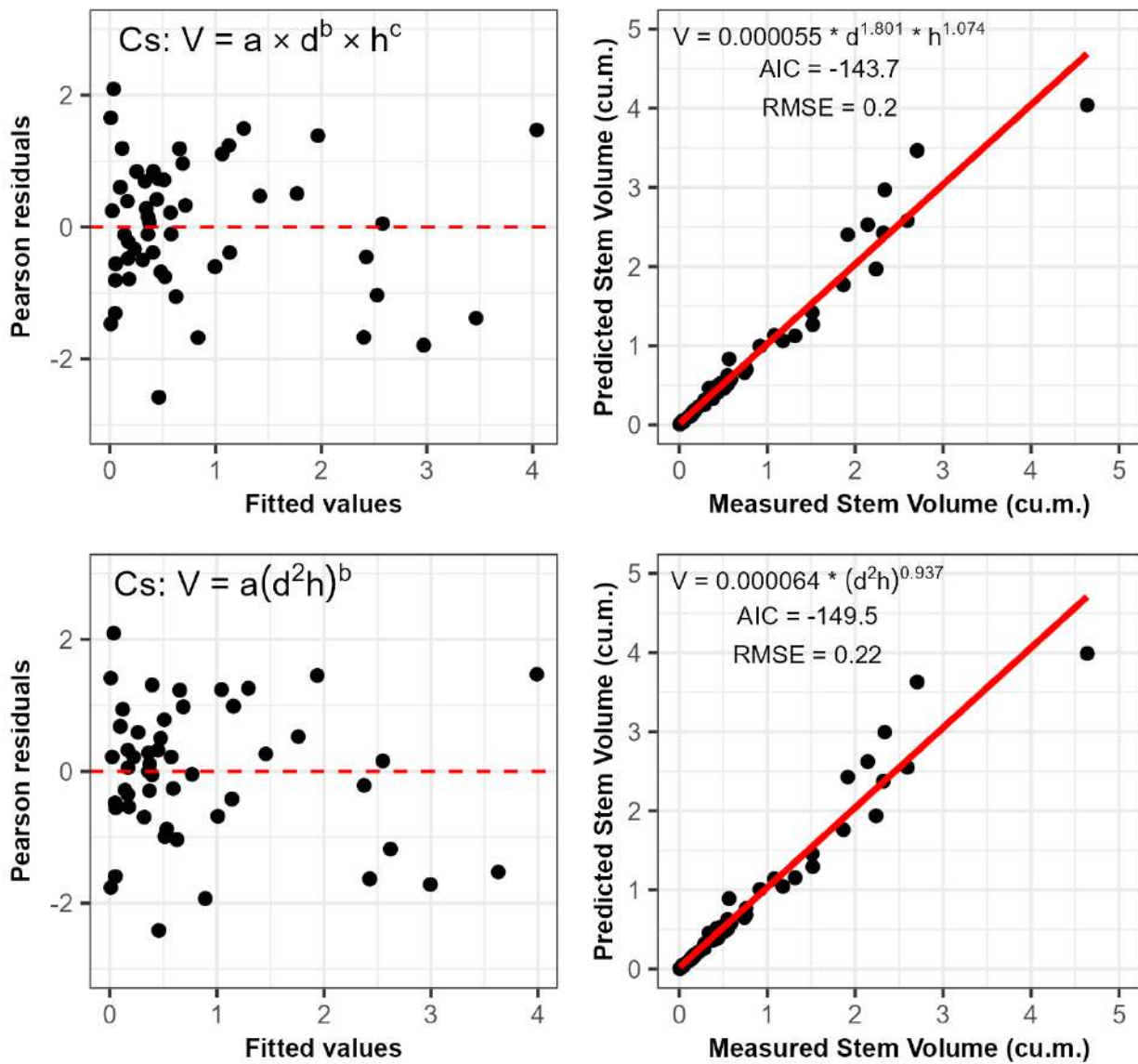
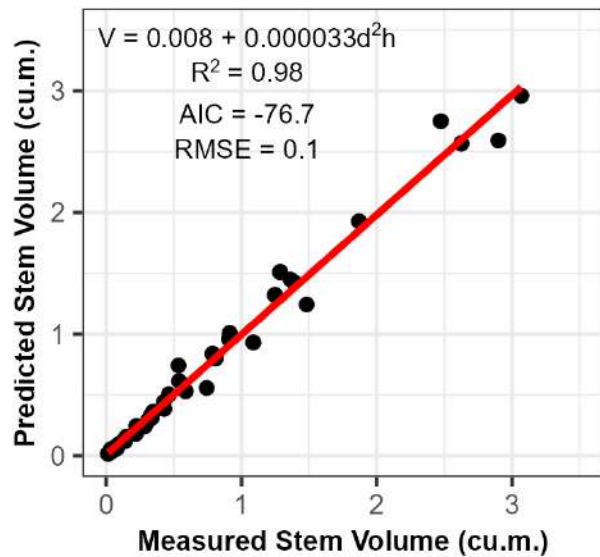
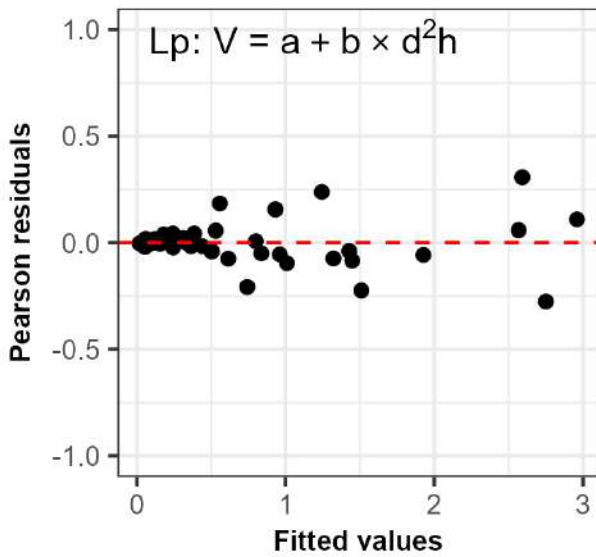
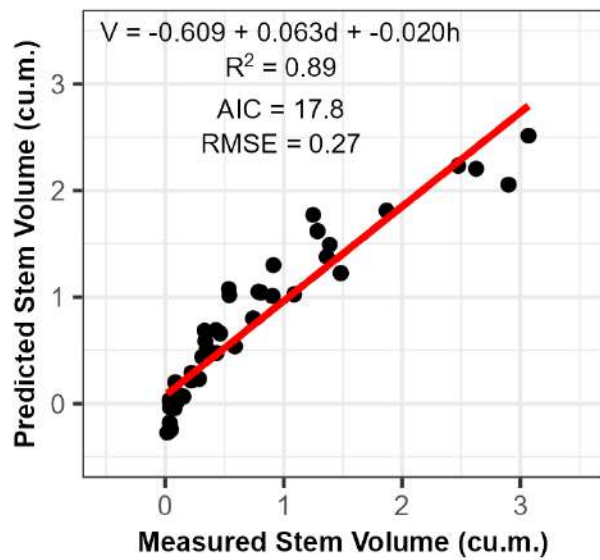
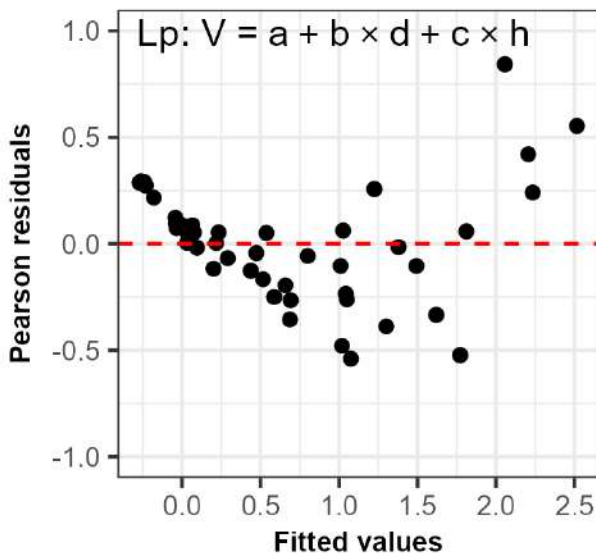
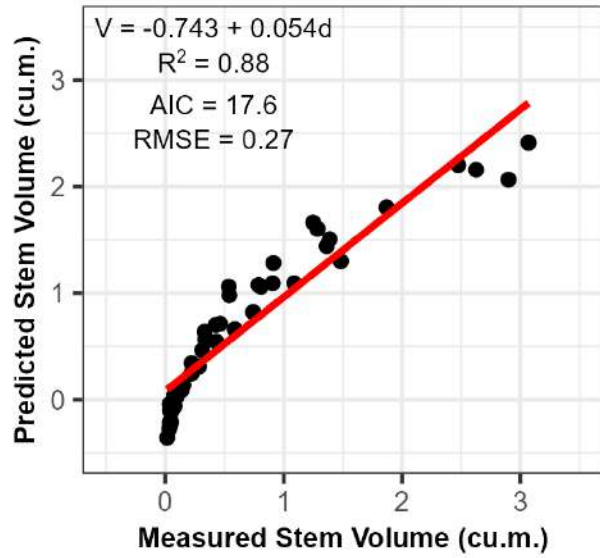
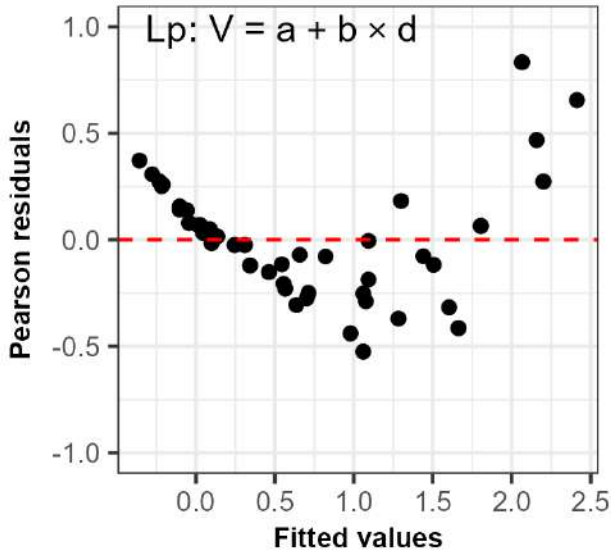


Figure A3.2: Left figures show the Pearson's residuals versus fitted values, indicating the distribution of errors, while right figures show the relationship between predicted versus the measured total stem volume of *Castanopsis* spp. Models' performance is summarized by the equations, AIC, and RMSE for each model in the right figures. For tree code (An, Cs, Lp, Sw, Pr, Sr, Ta) refer Table 1.

Table A3.3: Summary of performance metrics for candidate models of *Lagerstroemia parviflora*. (All displayed parameters are significant at 5%).

Model	Equation	n	a	b	c	AIC	R ²	RMSE	MB
M1	$V = a + b * d$	46	-0.743143	0.054318	-	17.63	0.89	0.28	-
M2	$V = a + b * d + c * h$	46	-0.608506	0.06293	-0.020103	17.82	0.89	0.27	-
M3	$V = a + b * d^2h$	46	0.008094	0.000033	-	-76.72	0.99	0.1	-
M4	$V = a * d^b$	46	0.000132	2.488433	-	-111.7	-	0.15	-0.01
M5	$V = a * d^b * h^c$	46	0.000059	1.811048	1.03294	-149.1	-	0.11	0.02
M6	$V = a * (d^2h)^b$	46	0.000064	0.936459	-	-156.5	-	0.11	0.01



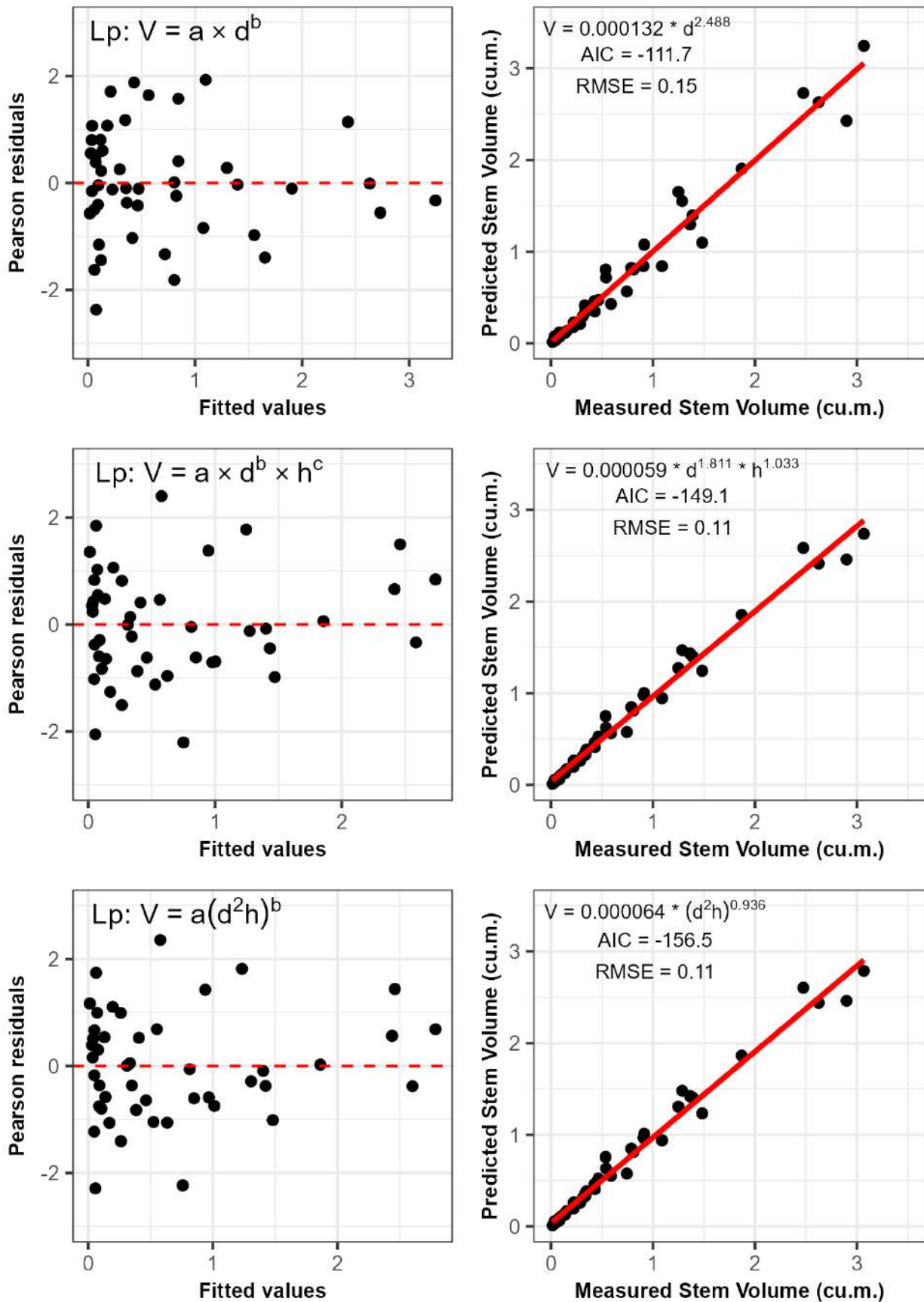
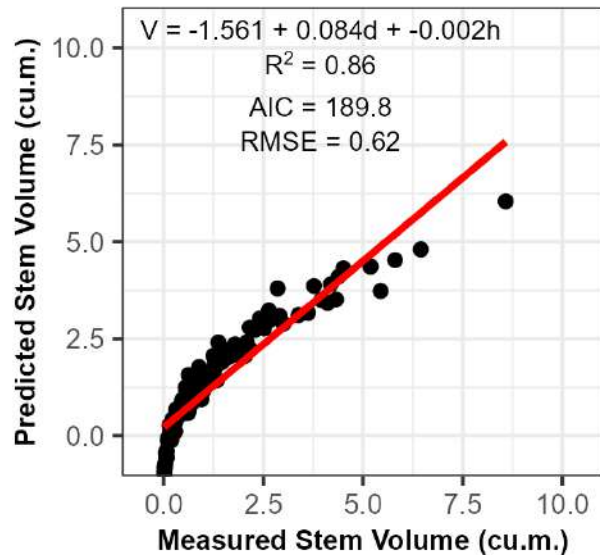
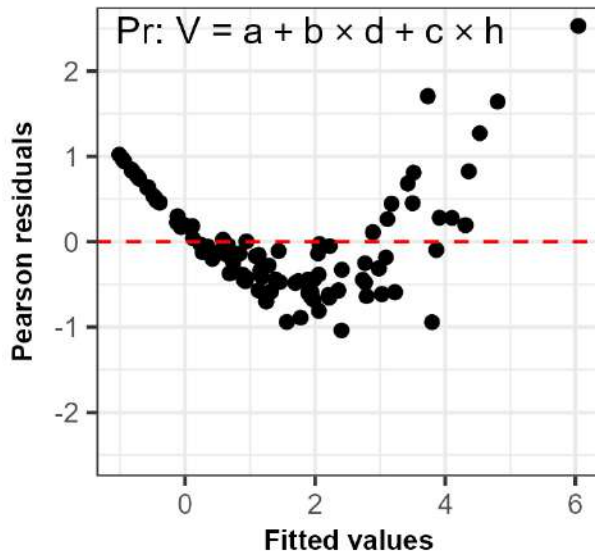
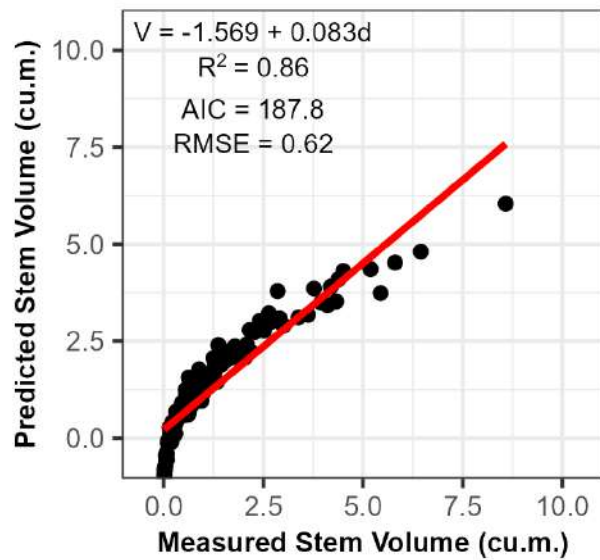
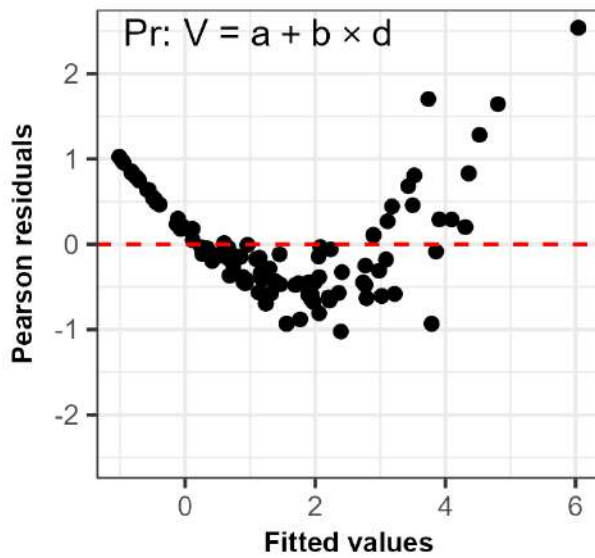
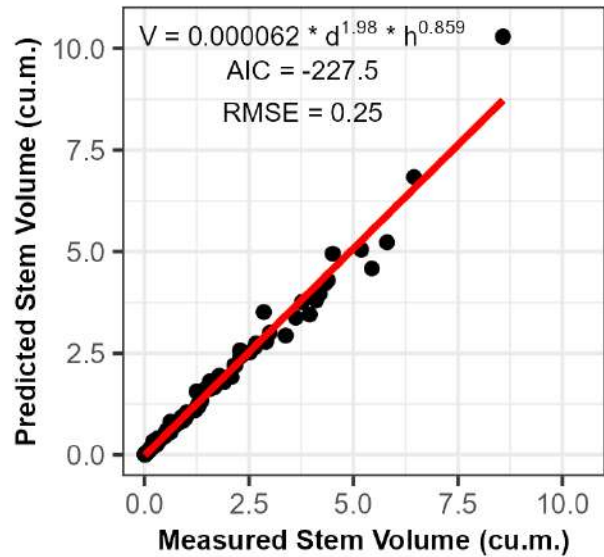
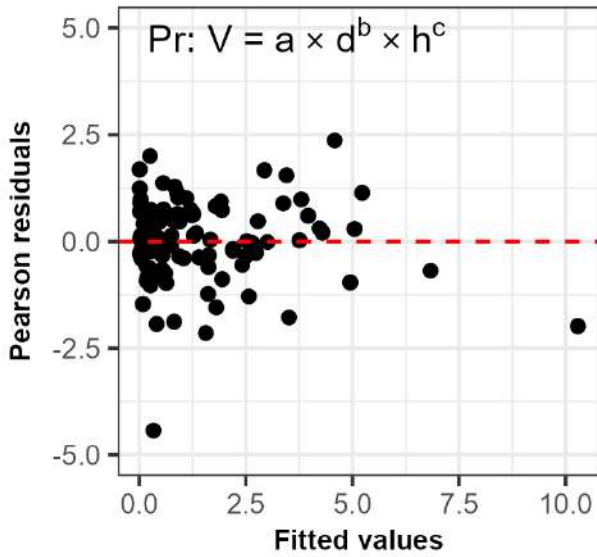
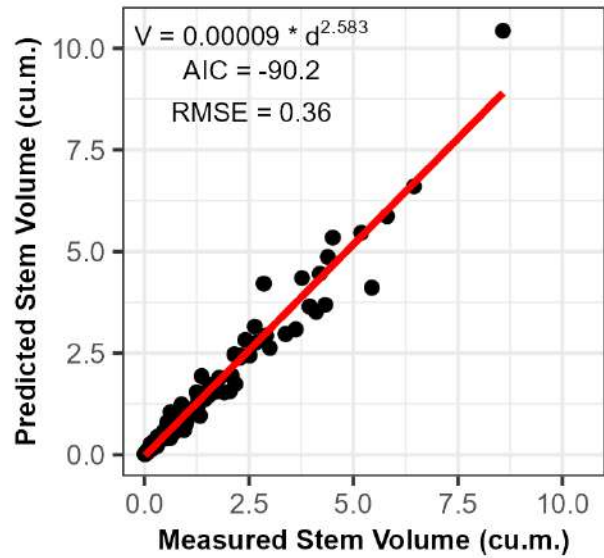
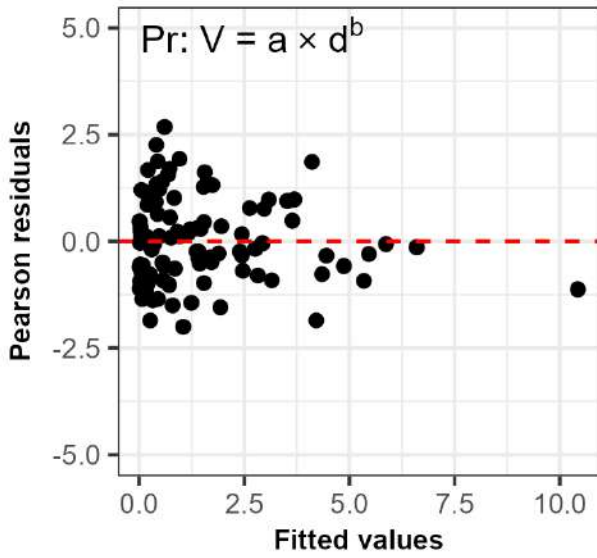
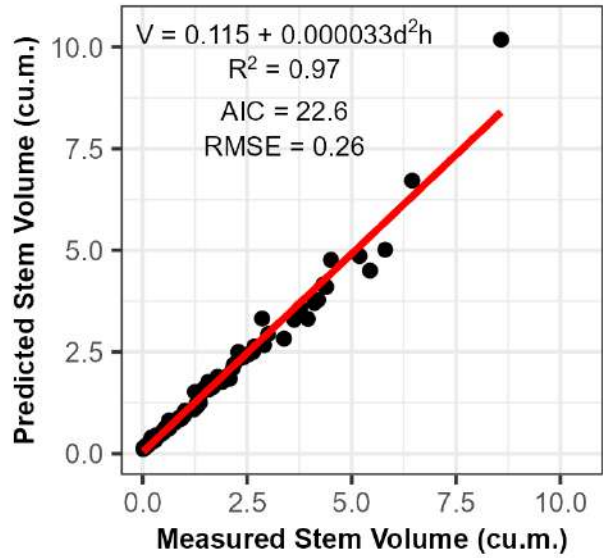
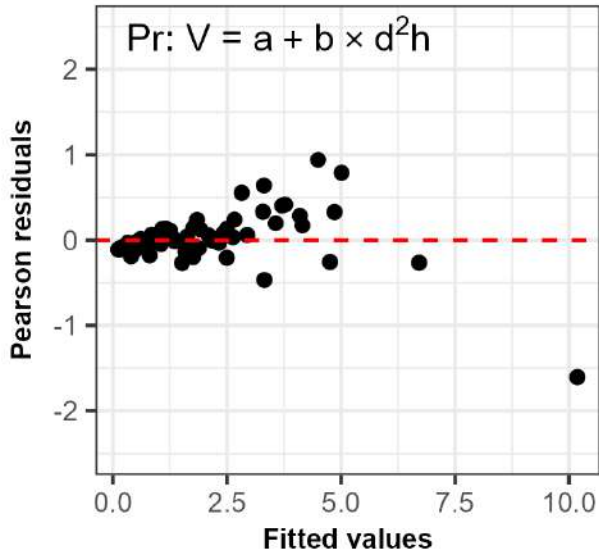


Figure A3.3: Left figures show the Pearsons residuals versus fitted values, indicating the distribution of errors, while right figures show the relationship between predicted versus the measured total stem volume of *Lagerstroemia parviflora*. Models' performance is summarized by the equations, AIC, and RMSE for each model in the right figures. For tree code (An, Cs, Lp, Sw, Pr, Sr, Ta) refer Table 1.

Table A3.4: Summary of performance metrics for candidate models of *Pinus roxburghii*. (All displayed parameters are significant at 5%).

Model	Equation	n	a	b	c	AIC	R ²	RMSE	MB
M1	$V = a + b * d$	96	-1.569476	0.083463	-	187.81	0.86	0.63	-
M2	$V = a + b * d + c * h$	96	-1.560502	0.08402	-0.001547	189.8	0.86	0.63	-
M3	$V = a + b * d^2h$	96	0.114874	0.000033	-	22.59	0.98	0.27	-
M4	$V = a * d^b$	96	0.00009	2.583496	-	-90.2	-	0.36	-0.03
M5	$V = a * d^b * h^c$	96	0.000062	1.97957	0.859198	-227.5	-	0.25	-0.01
M6	$V = a * (d^2h)^b$	96	0.000058	0.9573	-	-232	-	0.25	0.01





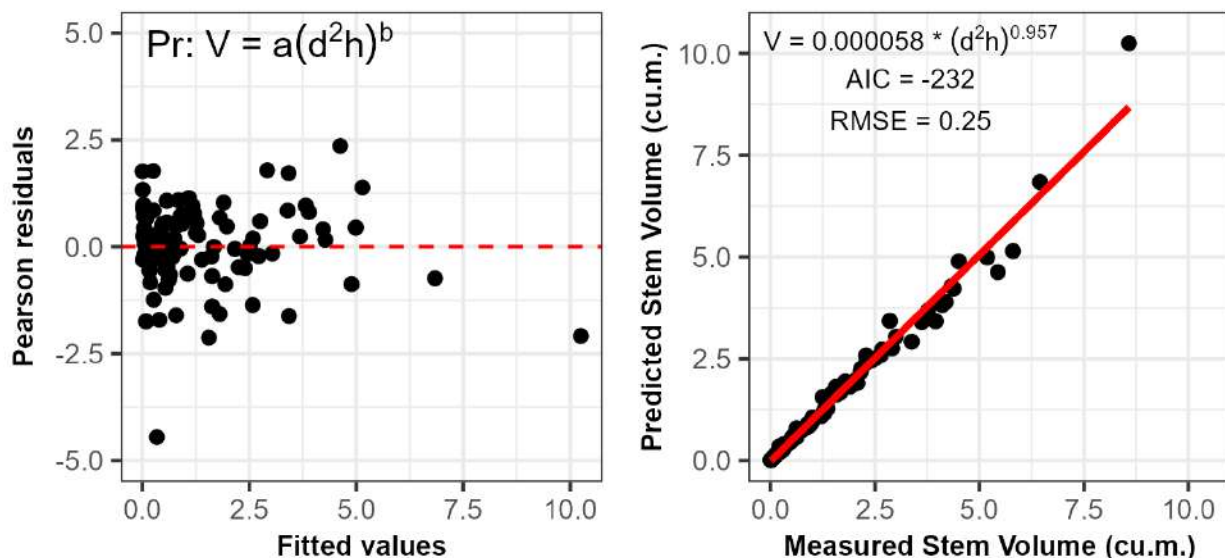
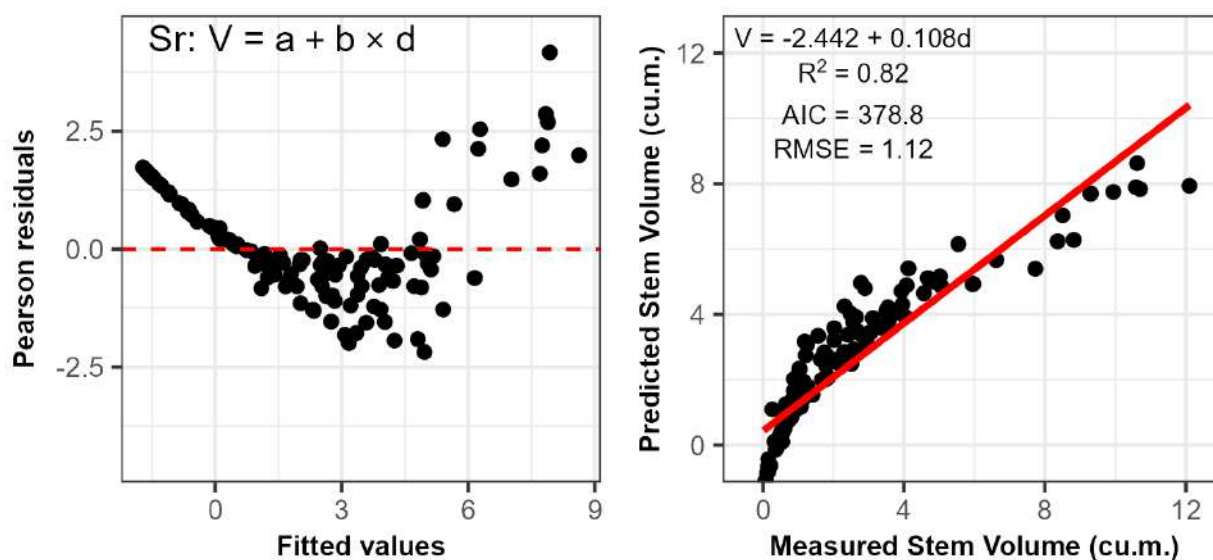
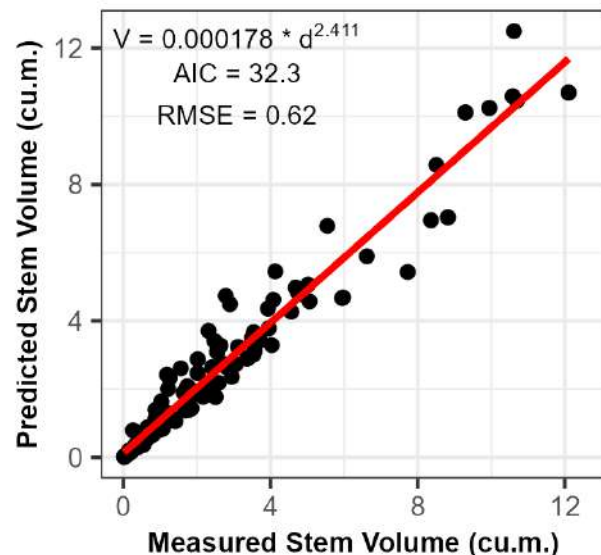
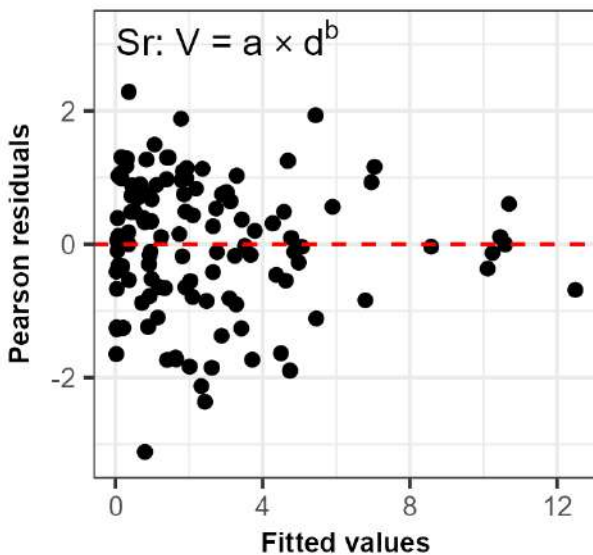
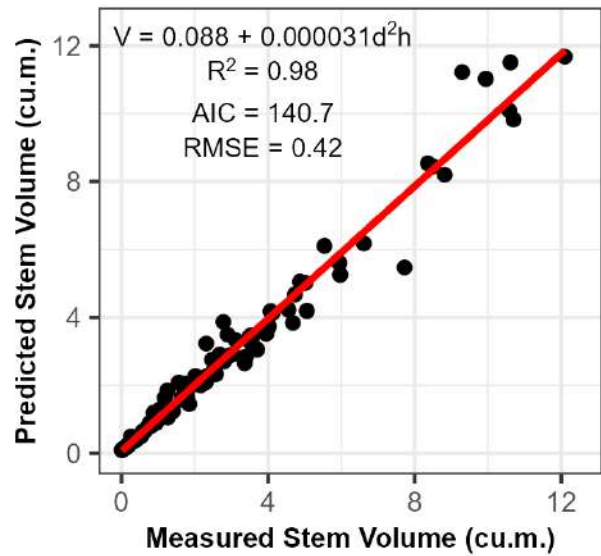
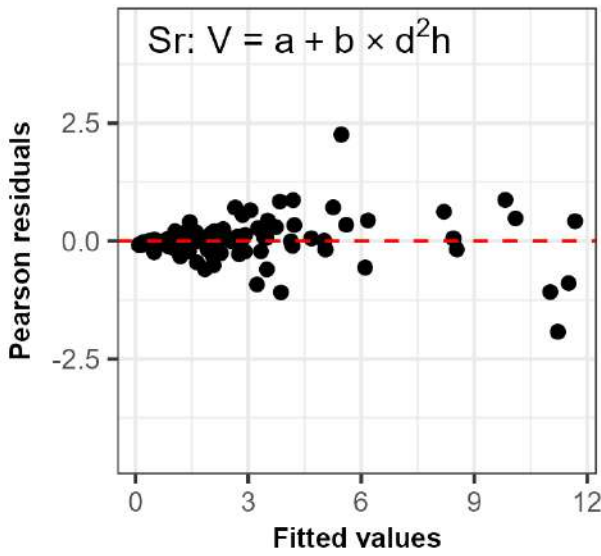
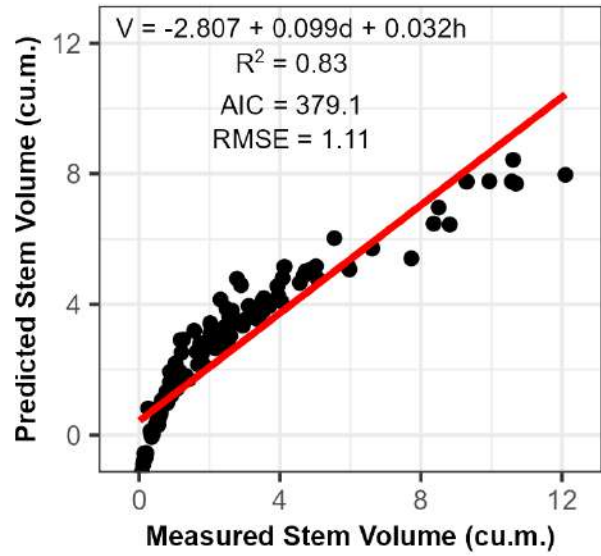
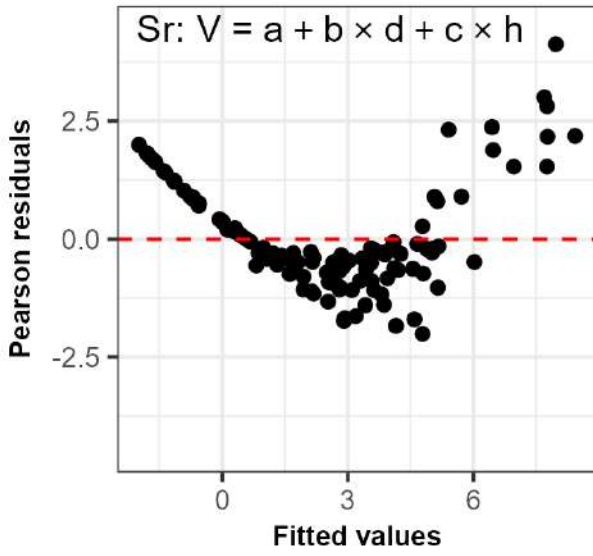


Figure A3.4: Left figures show the Pearsons residuals versus fitted values, indicating the distribution of errors, while right figures show the relationship between predicted versus the measured total stem volume of *Pinus roxburghii*. Models' performance is summarized by the equations, AIC, and RMSE for each model in the right figures. For tree code (An, Cs, Lp, Sw, Pr, Sr, Ta) refer Table 1.

Table A3.5: Summary of performance metrics for candidate models of *Shorea robusta*. (All displayed parameters are significant at 5%).

Model	Equation	n	a	b	c	AIC	R ²	RMSE	MB
M1	$V = a + b * d$	122	-2.44234	0.1081	-	378.85	0.83	1.12	-
M2	$V = a + b * d + c * h$	122	-2.807302	0.098779	0.032121	379.07	0.83	1.11	-
M3	$V = a + b * d^2h$	122	0.087555	0.000031	-	140.7	0.98	0.43	-
M4	$V = a * d^b$	122	0.000178	2.411132	-	32.3	-	0.62	-0.03
M5	$V = a * d^b * h^c$	122	0.000052	1.840502	1.051822	-126.6	-	0.41	0.04
M6	$V = a * (d^2h)^b$	122	0.000059	0.948535	-	-131.9	-	0.41	0.02





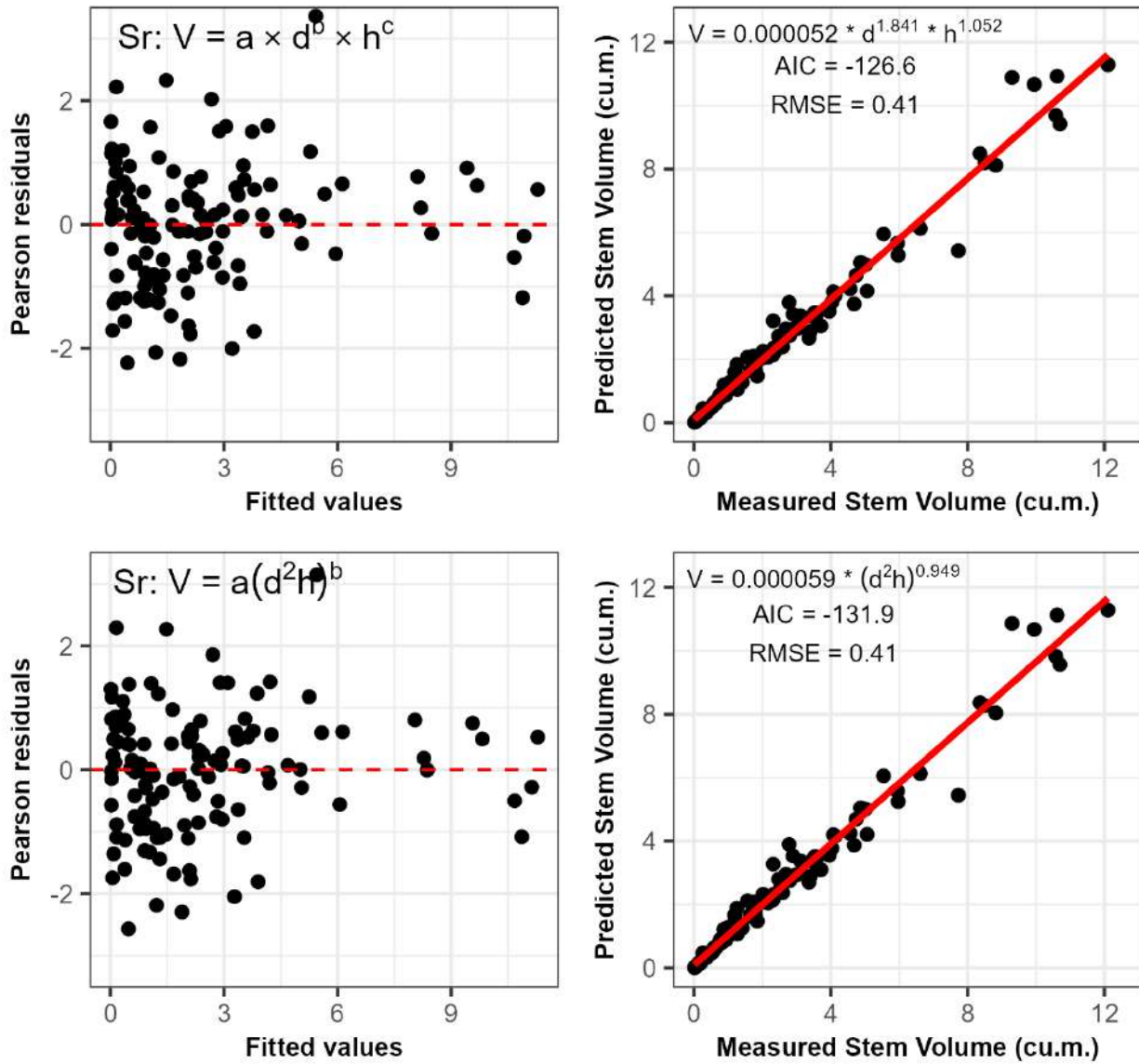
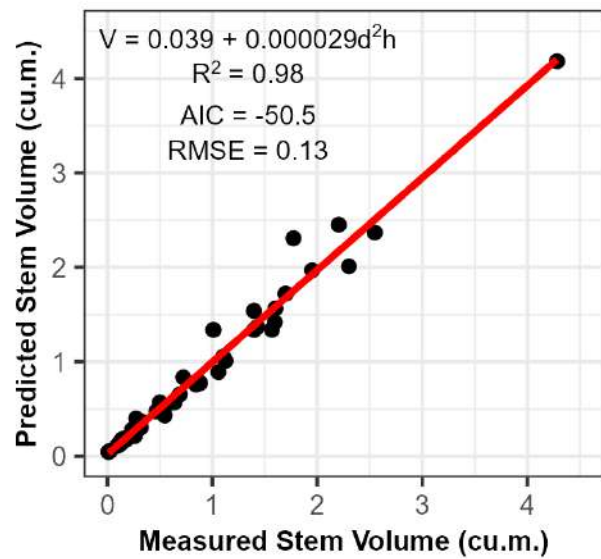
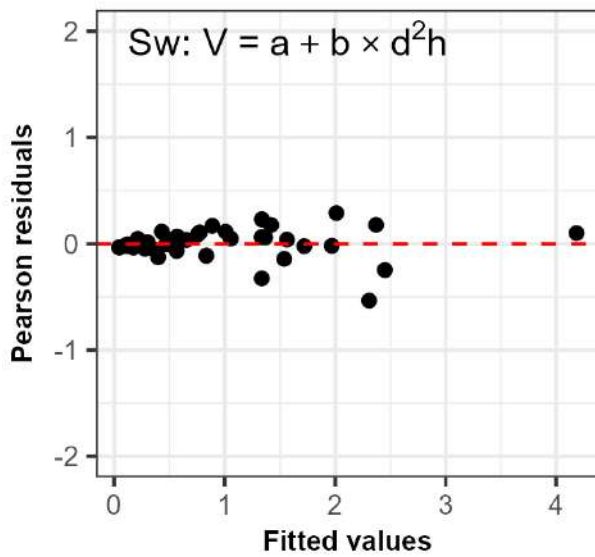
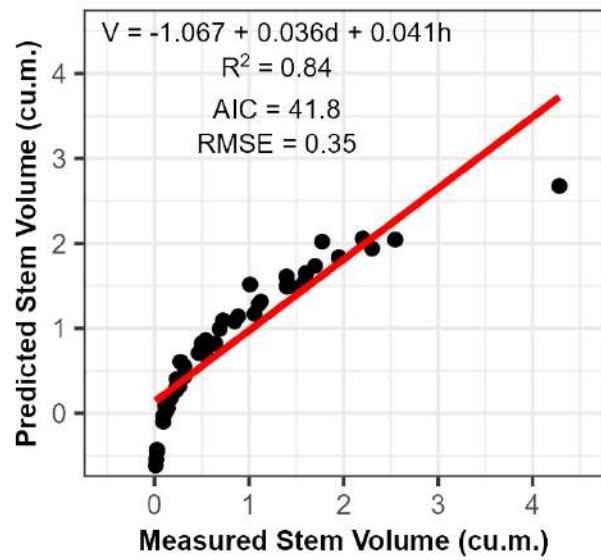
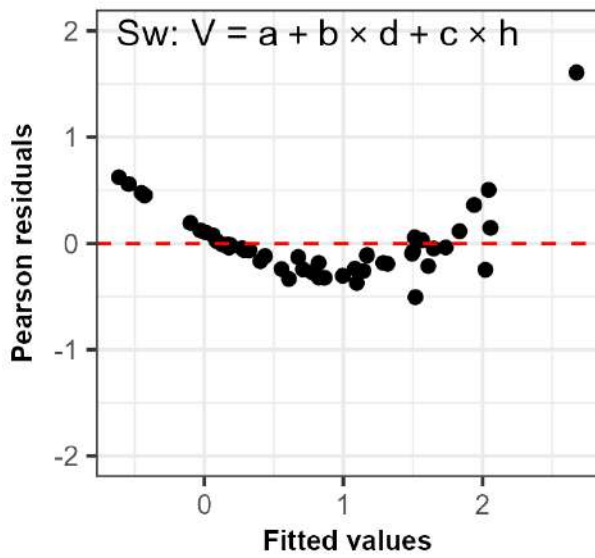
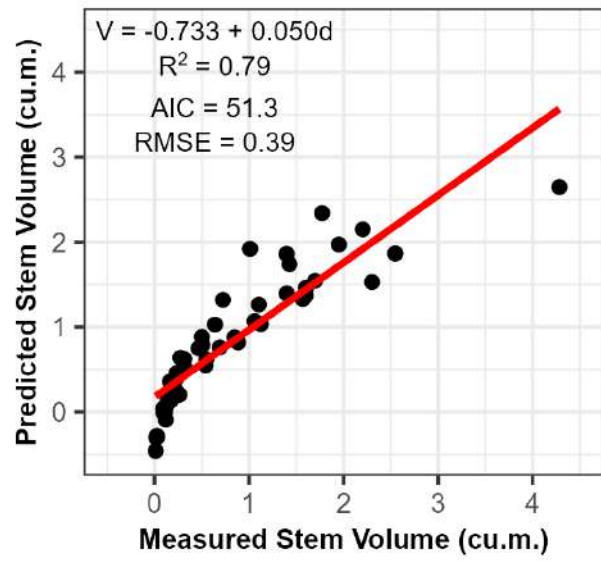
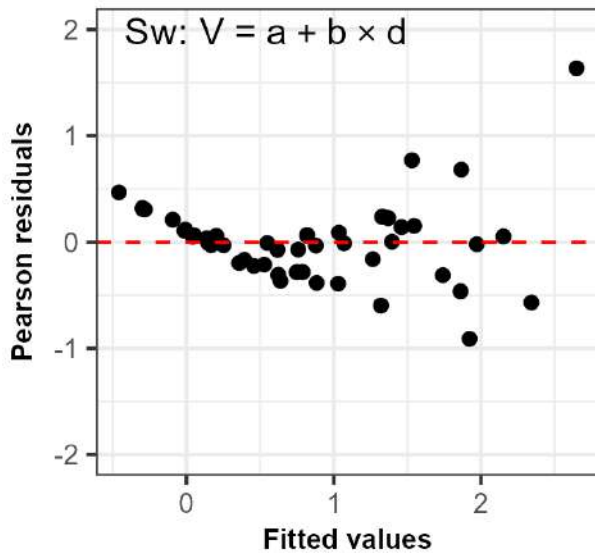


Figure A3.5: Left figures show the Pearsons residuals versus fitted values, indicating the distribution of errors, while right figures show the relationship between predicted versus the measured total stem volume of *Shorea robusta*. Models' performance is summarized by the equations, AIC, and RMSE for each model in the right figures. For tree code (An, Cs, Lp, Sw, Pr, Sr, Ta) refer Table 1.

Table A3.6: Summary of performance metrics for candidate models of *Schima wallichii*. (All displayed parameters are significant at 5%).

Model	Equation	n	a	b	c	AIC	R ²	RMSE	MB
M1	$V = a + b * d$	47	-0.733009	0.050073	-	51.31	0.8	0.4	-
M2	$V = a + b * d + c * h$	47	-1.066692	0.036492	0.041375	41.81	0.84	0.35	-
M3	$V = a + b * d^2h$	47	0.038973	0.000029	-	-50.54	0.98	0.14	-
M4	$V = a * d^b$	47	0.000162	2.393001	-	-46.9	-	0.36	-0.03
M5	$V = a * d^b * h^c$	47	0.000047	1.677002	1.25495	-138.8	-	0.08	-0.01
M6	$V = a * (d^2h)^b$	47	0.000069	0.926612	-	-130.2	-	0.14	-0.02



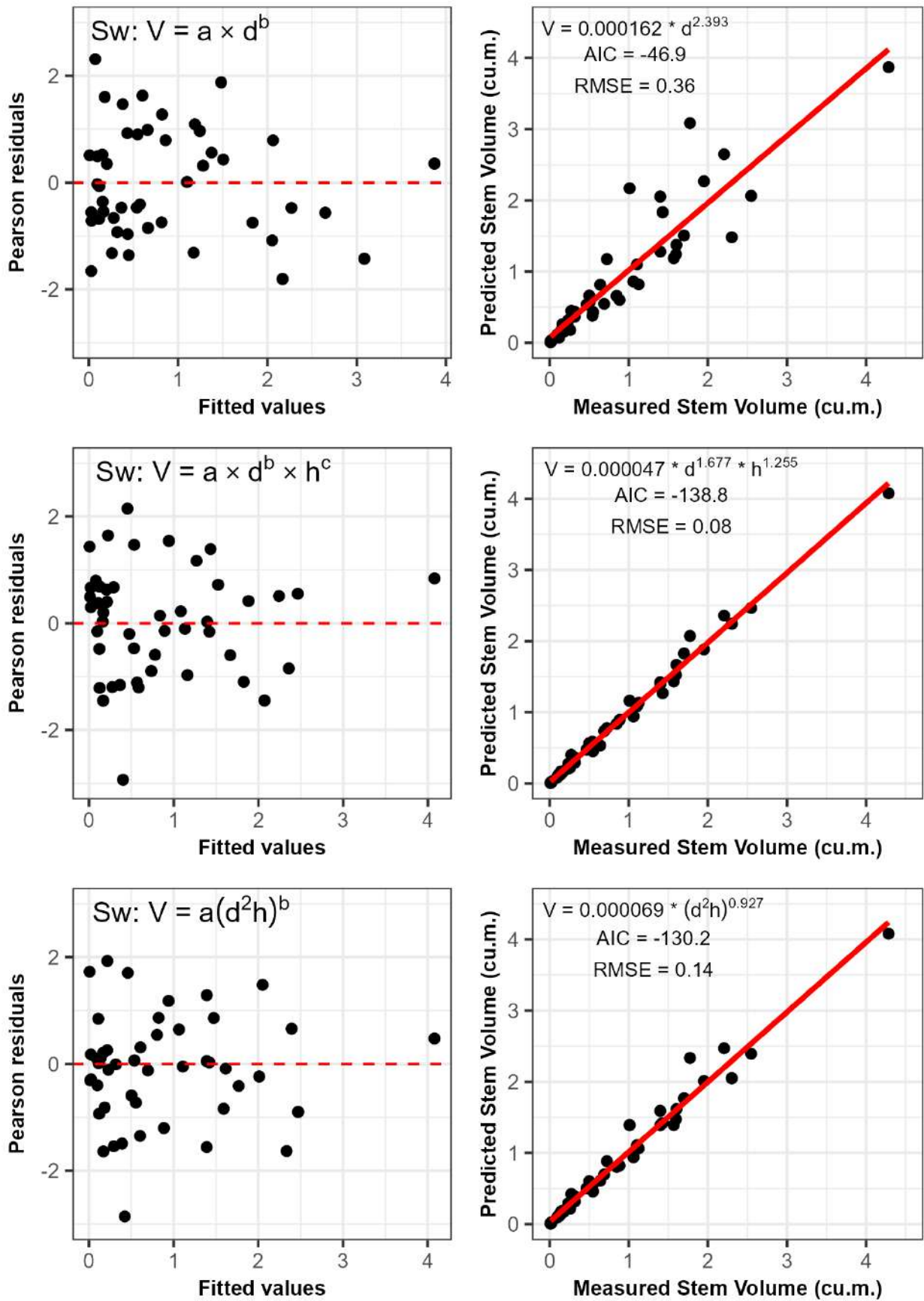
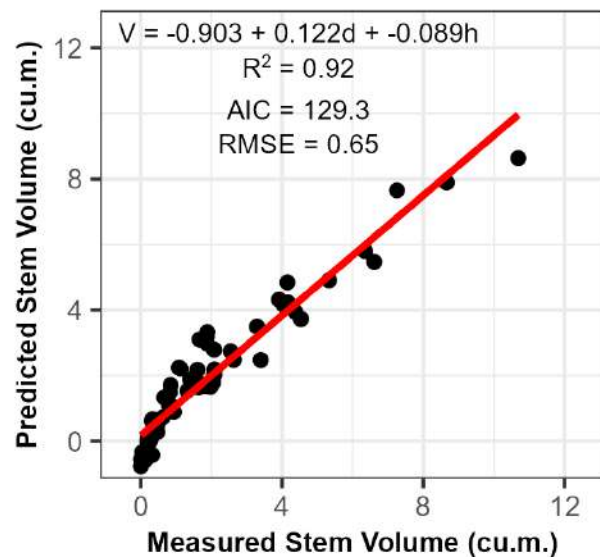
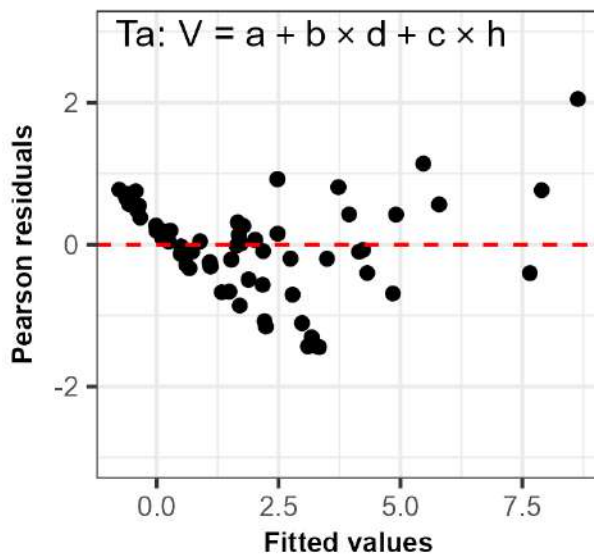
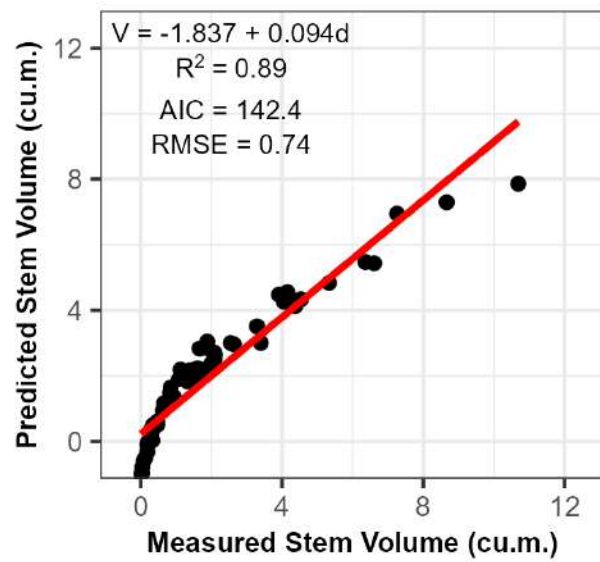
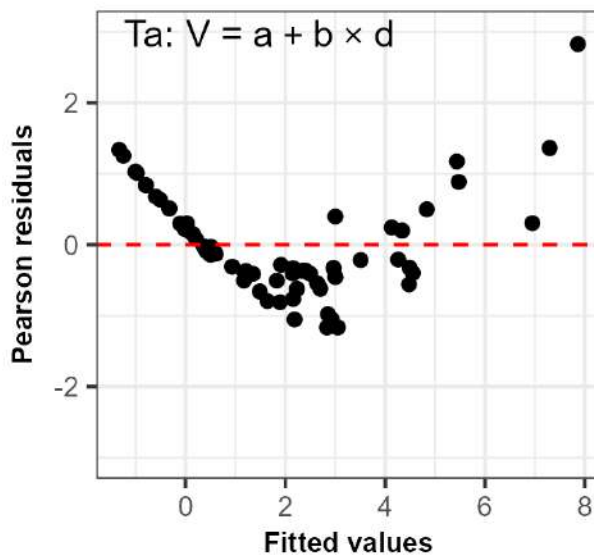
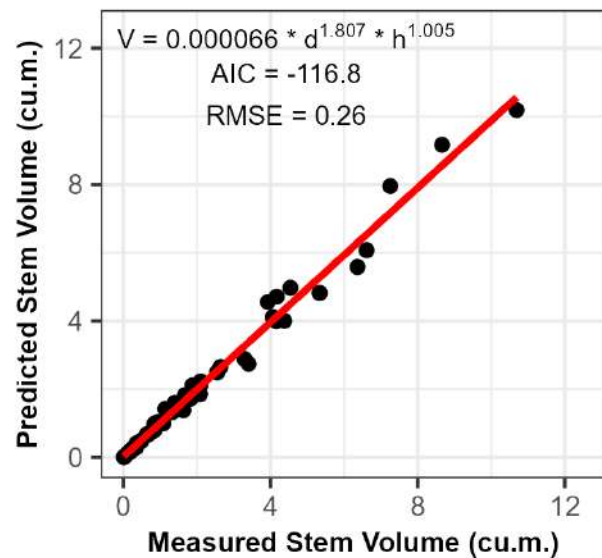
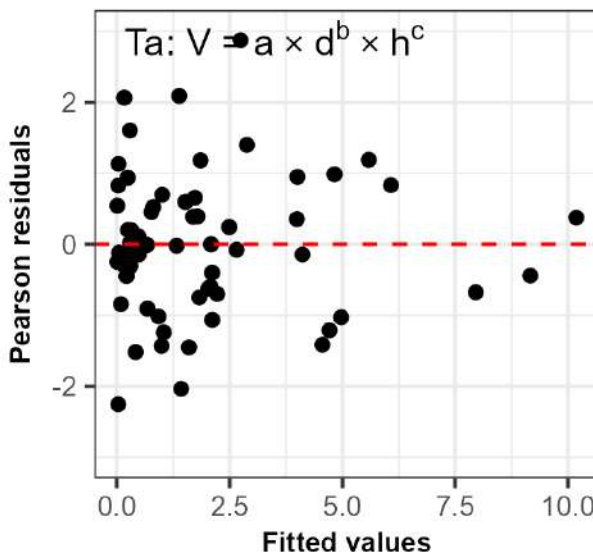
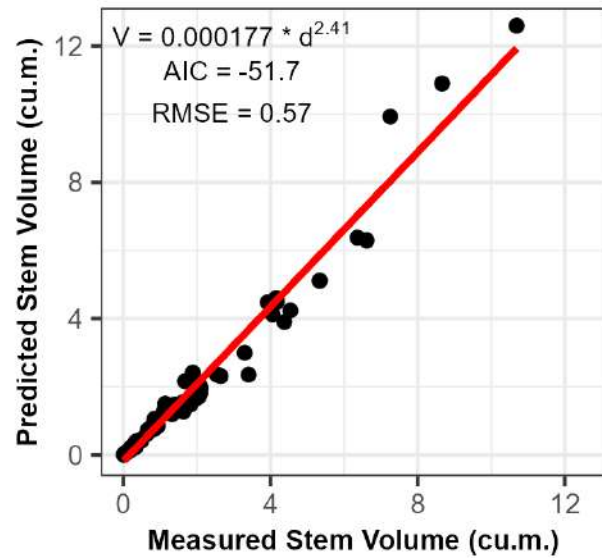
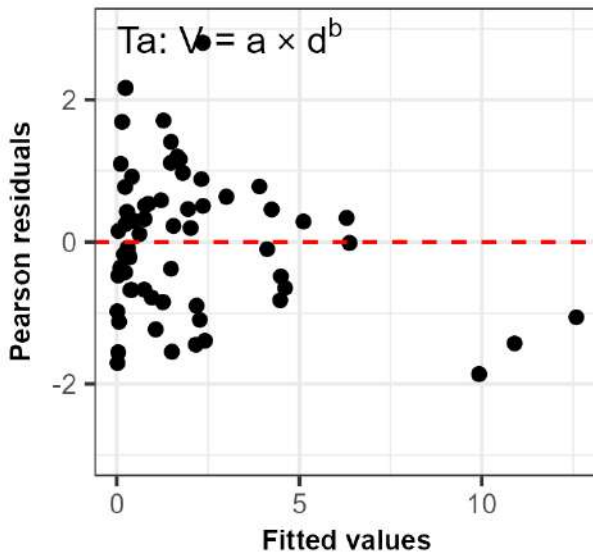
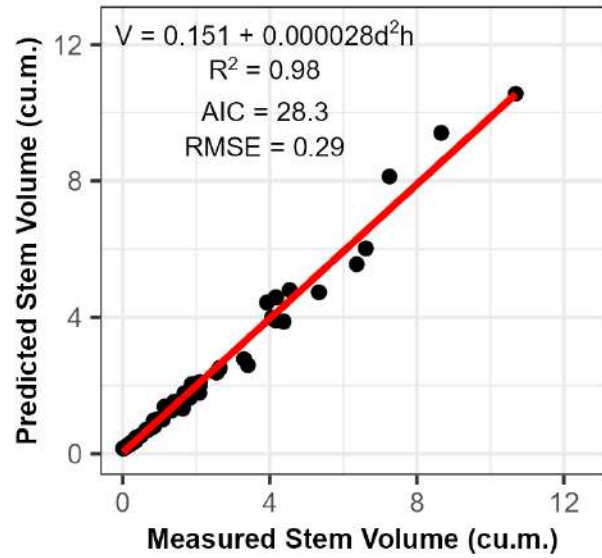
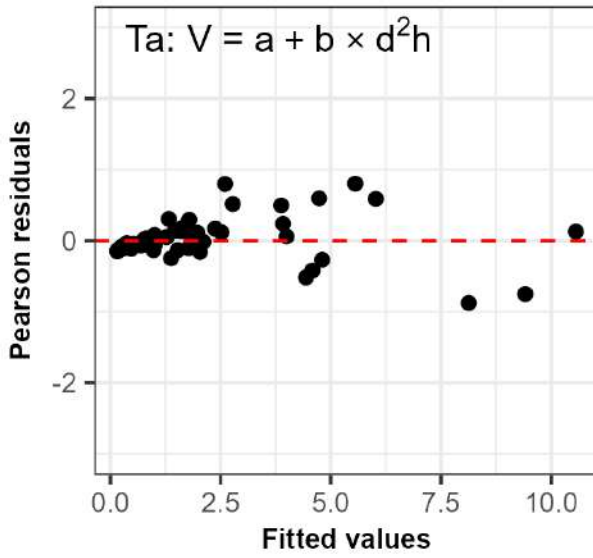


Figure A3.6: Left figures show the Pearsons residuals versus fitted values, indicating the distribution of errors, while right figures show the relationship between predicted versus the measured total stem volume of *Schima wallichii*. Models' performance is summarized by the equations, AIC, and RMSE for each model in the right figures. For tree code (An, Cs, Lp, Sw, Pr, Sr, Ta) refer Table 1.

Table A3.7: Summary of performance metrics for candidate models of *Terminalia alata*. (All displayed parameters are significant at 5%).

Model	Equation	n	a	b	c	AIC	R ²	RMSE	MB
M1	$V = a + b \cdot d$	61	-1.836815	0.093969	-	142.45	0.9	0.75	-
M2	$V = a + b \cdot d + c \cdot h$	61	-0.902545	0.122412	-0.088867	129.34	0.92	0.66	-
M3	$V = a + b \cdot d^2h$	61	0.150834	0.000028	-	28.35	0.99	0.3	-
M4	$V = a \cdot d^b$	61	0.000177	2.409967	-	-51.7	-	0.57	-0.09
M5	$V = a \cdot d^b \cdot h^c$	61	0.000066	1.80687	1.004921	-116.8	-	0.26	0.01
M6	$V = a \cdot (d^2h)^b$	61	0.00007	0.928364	-	-124	-	0.27	-0.01





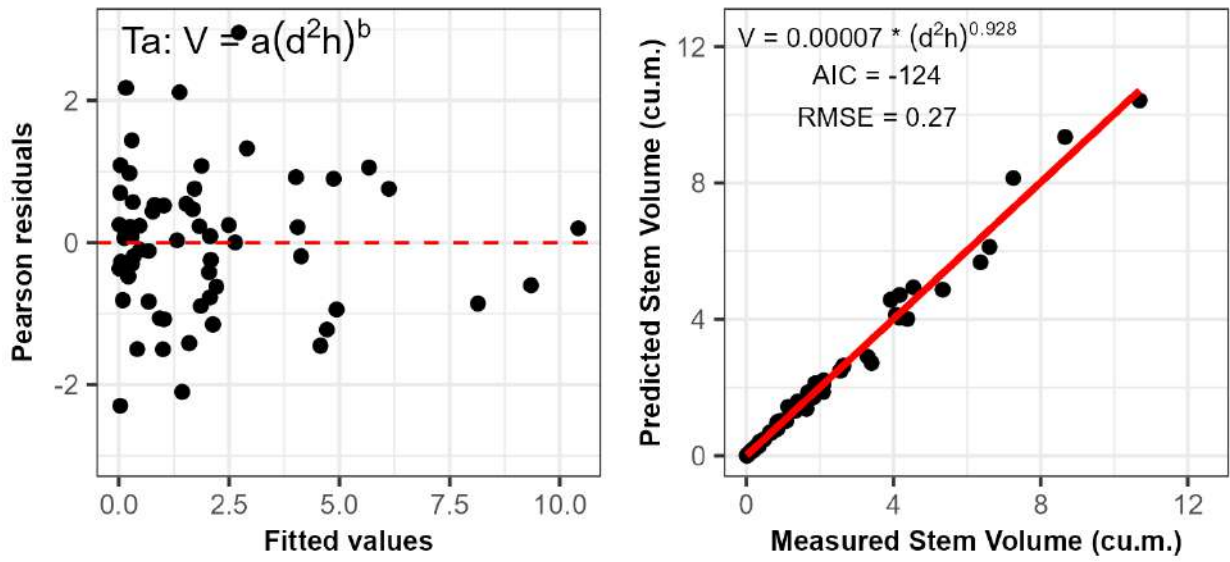


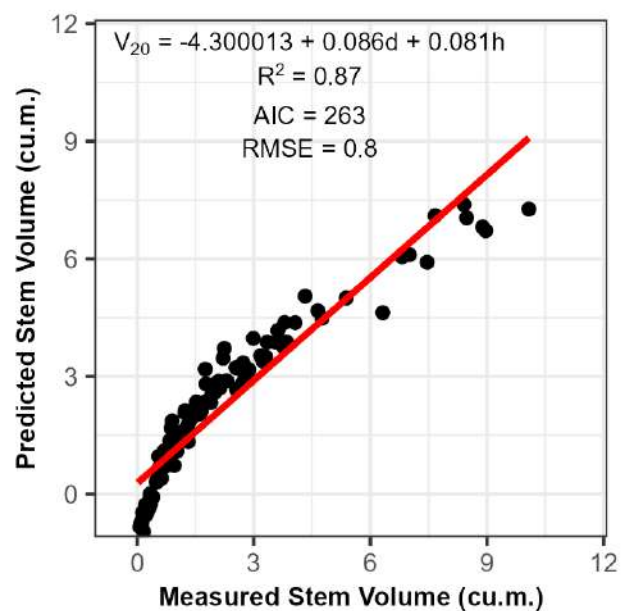
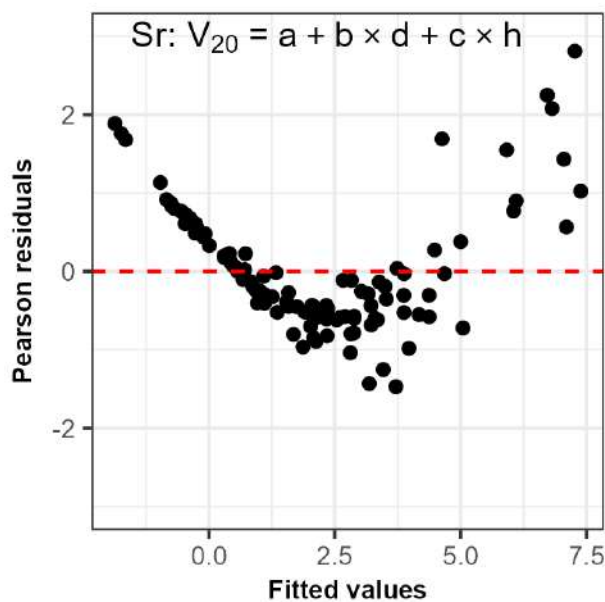
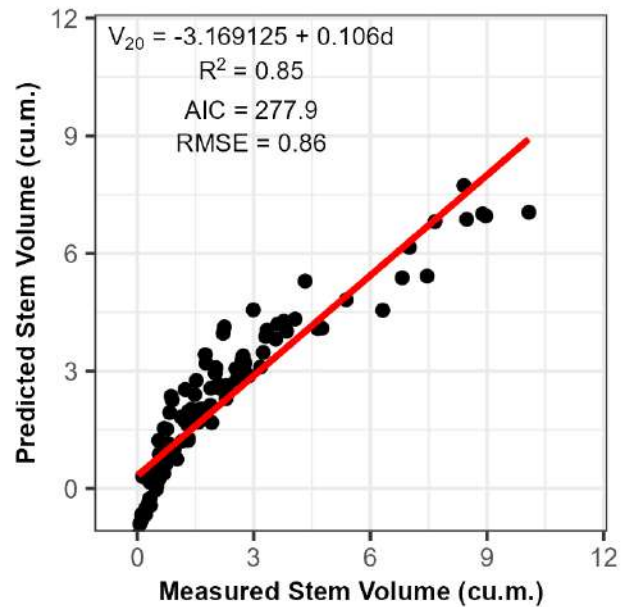
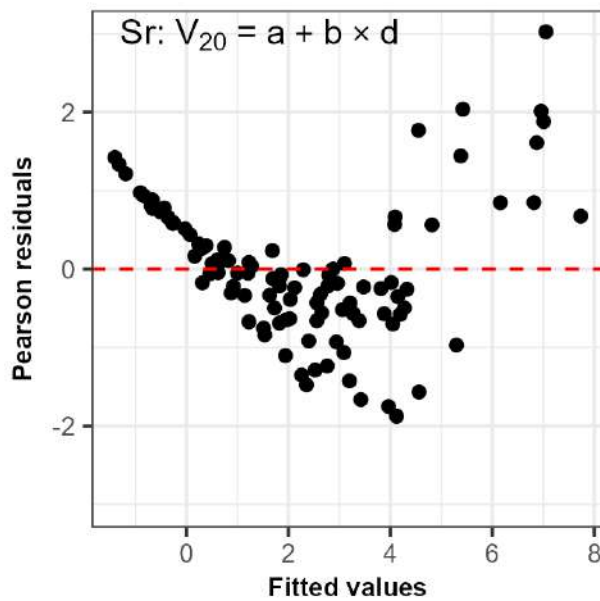
Figure A3.7: Left figures show the Pearsons residuals versus fitted values, indicating the distribution of errors, while right figures show the relationship between predicted versus the measured total stem volume of *Terminalia alata*. Models' performance is summarized by the equations, AIC, and RMSE for each model in the right figures. For tree code (An, Cs, Lp, Sw, Pr, Sr, Ta) refer Table 1.

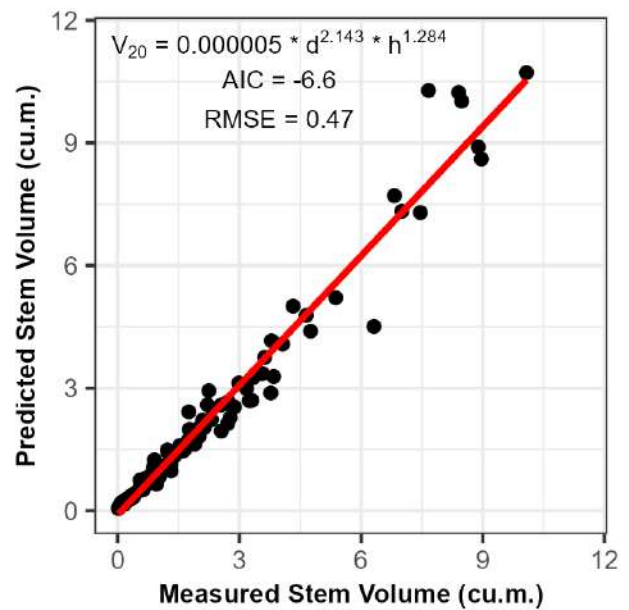
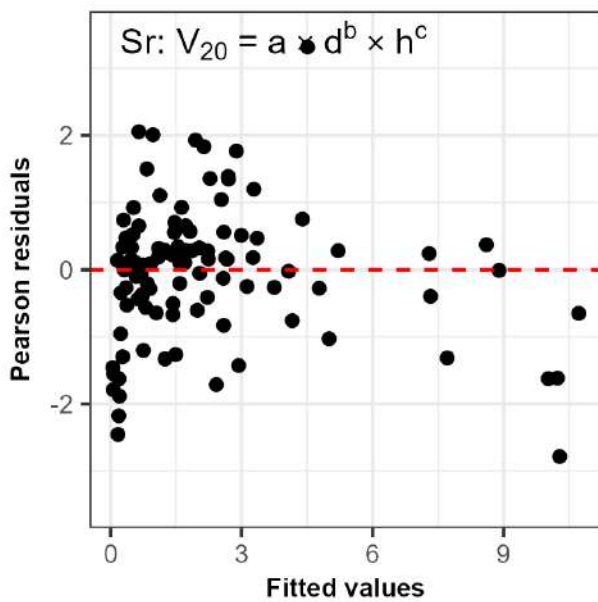
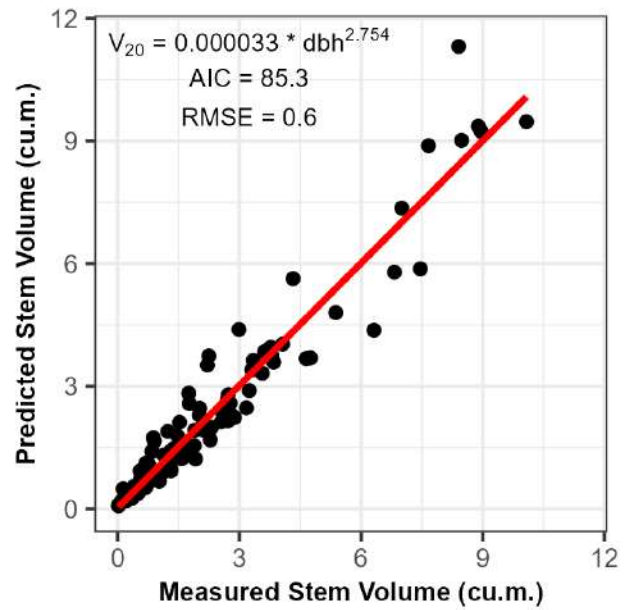
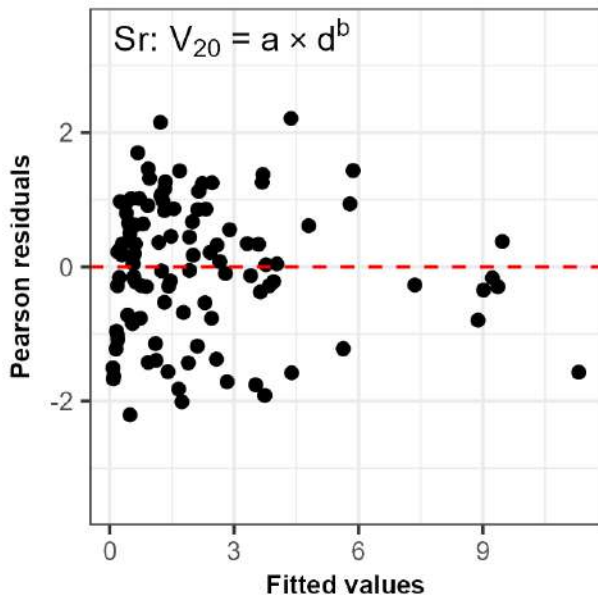
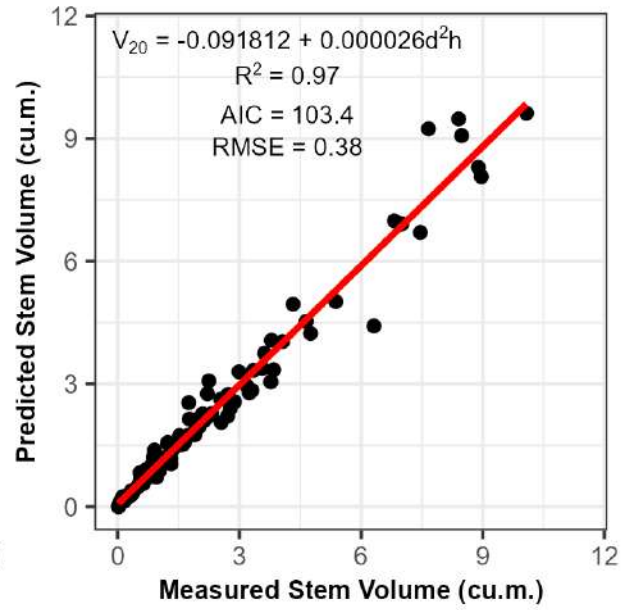
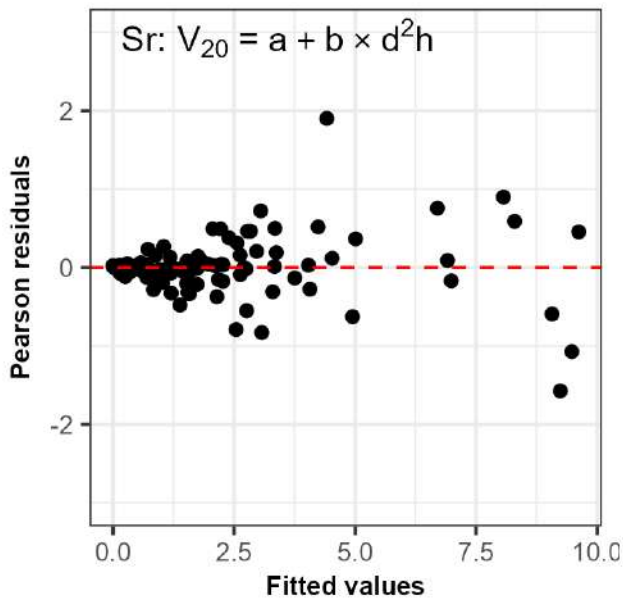
Annex IV

Volume Without Bark up to 20cm

Table A4.1: Summary of performance metrics for candidate models of *Shorea robusta* for volume (under bark) up to top 20cm (All displayed parameters are significant at 5%).

Model	Equation	n	a	b	c	AIC	RMSE	R ²	MB
M1	$V = a + b * d$	107	-3.16913	0.106447	-	277.92	0.86	0.85	-
M2	$V = a + b * d + c * h$	107	-4.30001	0.086447	0.0811	263.00	0.80	0.87	-
M3	$V = a + b * d^2h$	107	-0.09181	0.000026	-	103.36	0.38	0.97	-
M4	$V = a * d^b$	107	0.000033	2.754313	-	85.30	0.6	-	-0.02
M5	$V = a * d^b * h^c$	107	0.00005	2.142538	1.283593	-6.60	0.47	-	-0.02
M6	$V = a * (d^2h)^b$	107	0.000007	1.113125	-	-11.90	0.46	-	-0.03





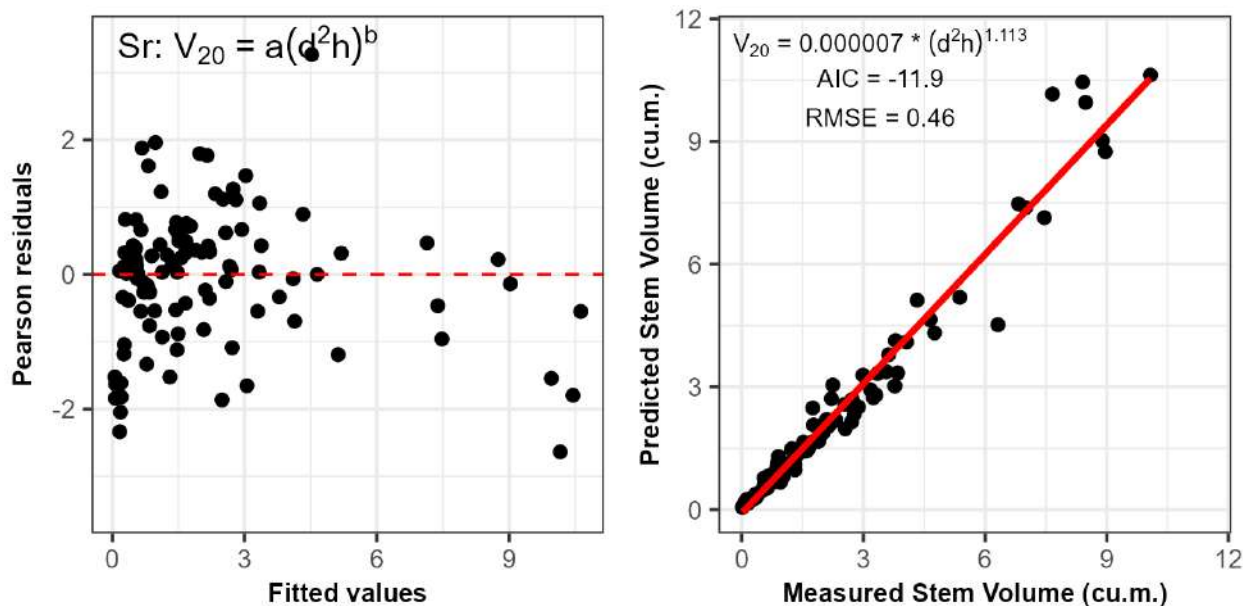
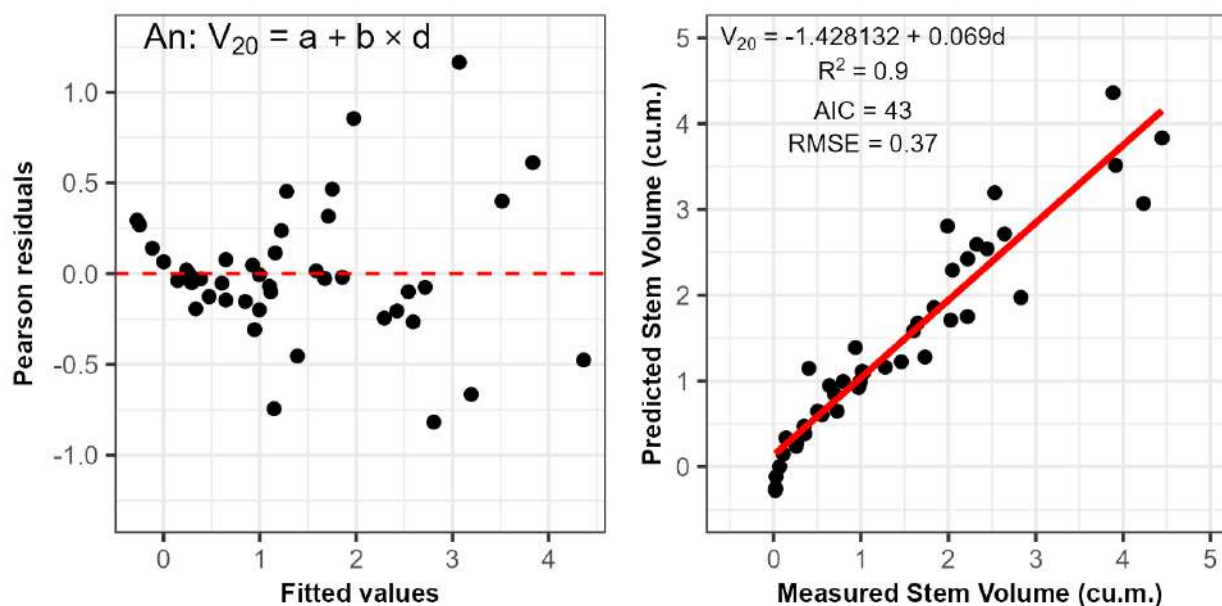


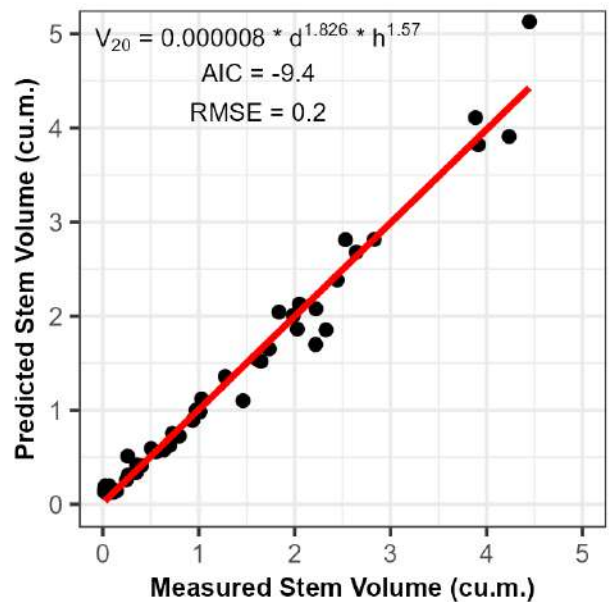
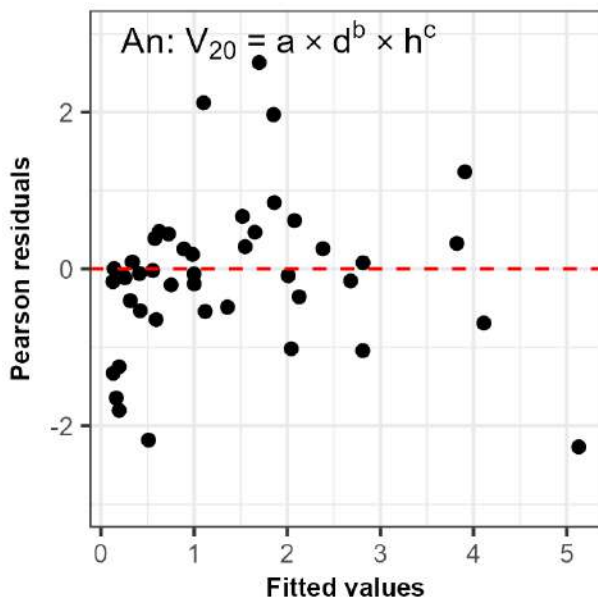
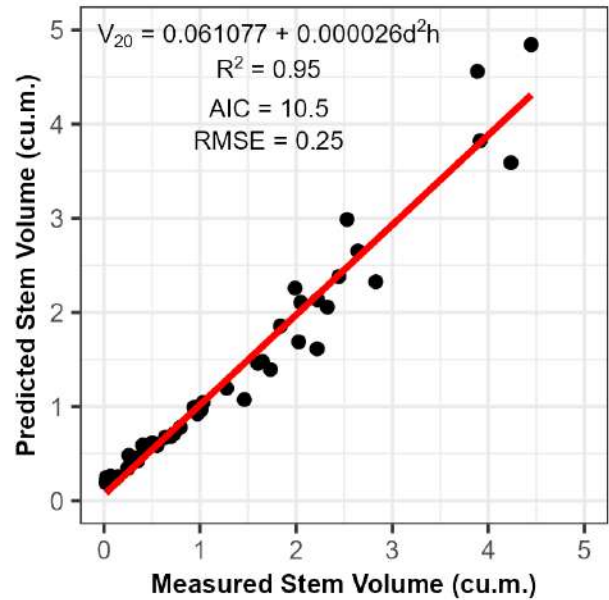
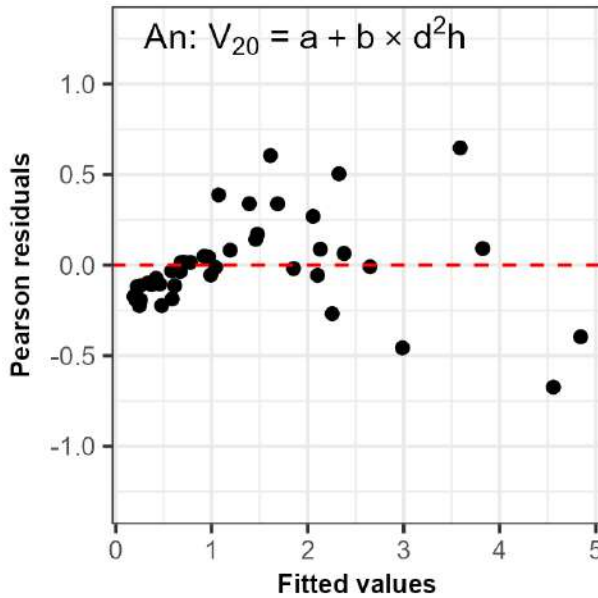
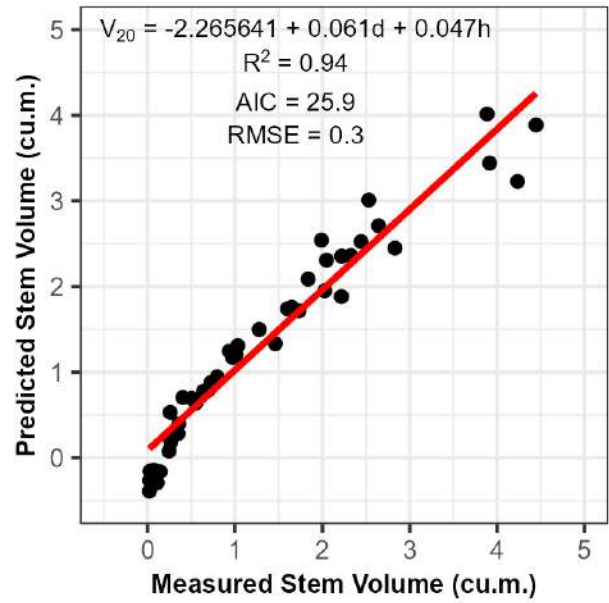
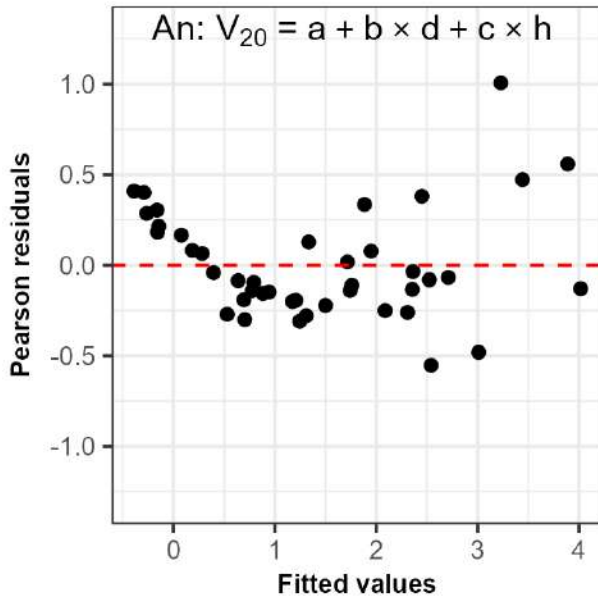
Figure A4.1: Left figures show the Pearsons residuals versus fitted values, indicating the distribution of errors, while right figures show the relationship between predicted versus the measured stem volume up to 20cm diameter of *Shorea robusta*. Models' performance is summarized by the equations, AIC, and RMSE for each model in the right figures. For tree code (An, Cs, Lp, Sw, Pr, Sr, Ta) refer Table 1.

Table A4.2: Summary of performance metrics for candidate models of *Alnus nepalensis* for volume (under bark) up to top 20cm. (All displayed parameters are significant at 5%).

Model	Equation	n	a	b	c	AIC	RMSE	R ²	MB
M1	$V = a + b * d$	43	-1.42813	0.069415	-	43.01	0.38	0.91	-
M2	$V = a + b * d + c * h$	43	-2.26564	0.061204	0.04688	25.93	0.3	0.94	-
M3	$V = a + b * d^2h$	43	0.061077	0.000026	-	10.47	0.26	0.96	-
M4	$V = a * d^b$	43	*	*	-	-	-	-	-
M5	$V = a * d^b * h^c$	43	0.000008	1.826485	1.570461	-9.4	0.2	-	-0.01
M6	$V = a * (d^2h)^b$	43	0.000023	1.016204	-	-2.3	0.28	-	-0.03

Note: * refers parameter not significant





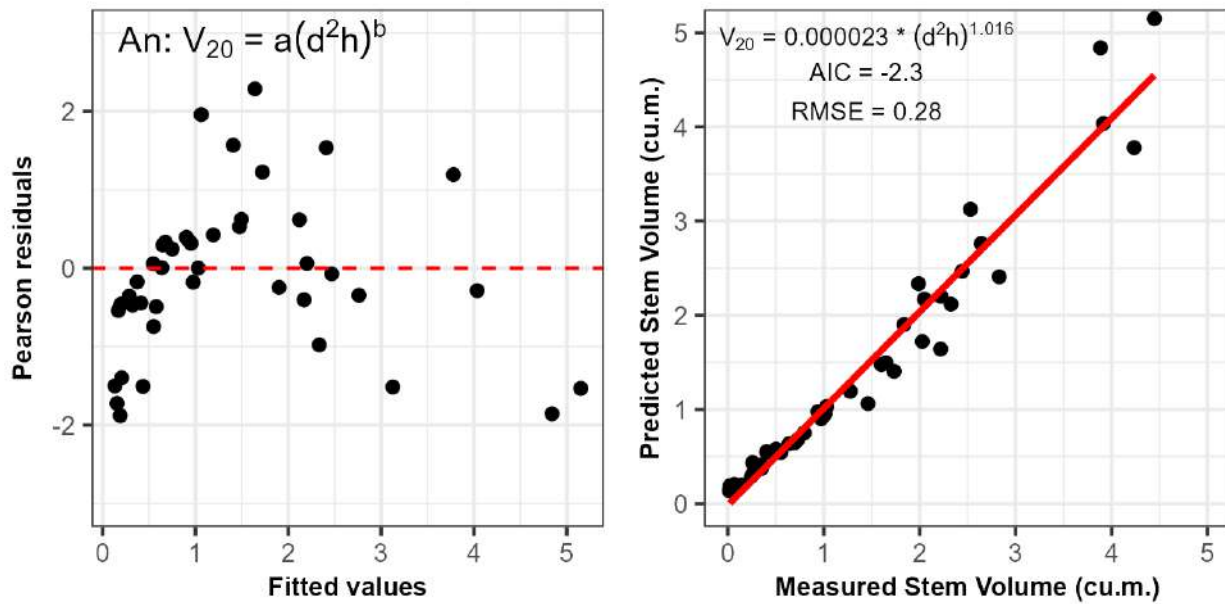
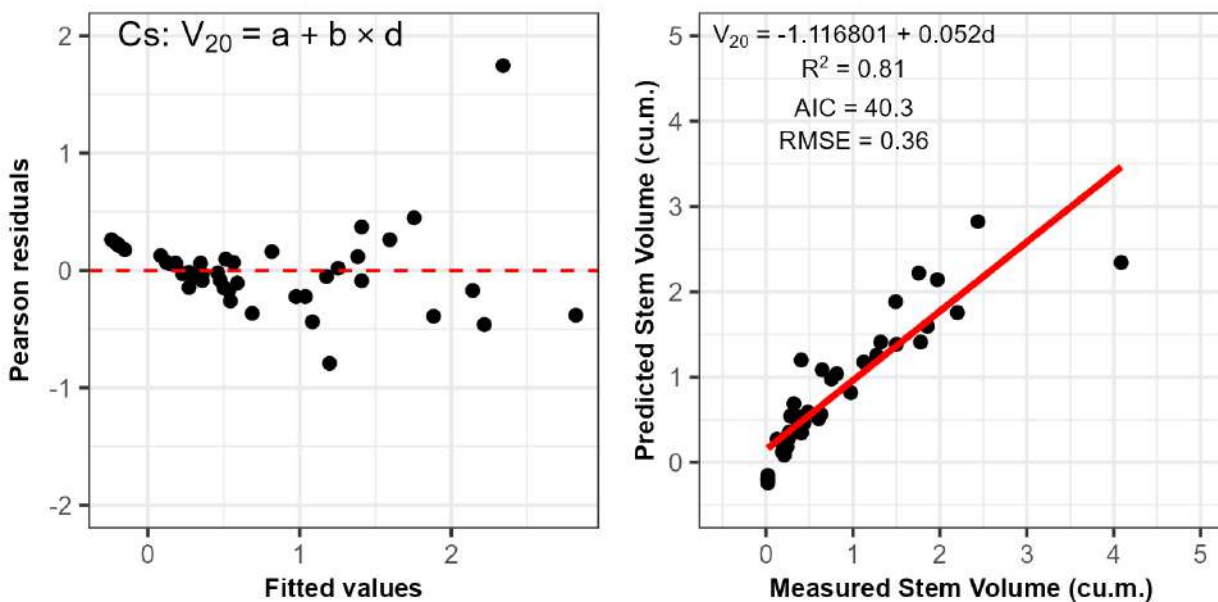
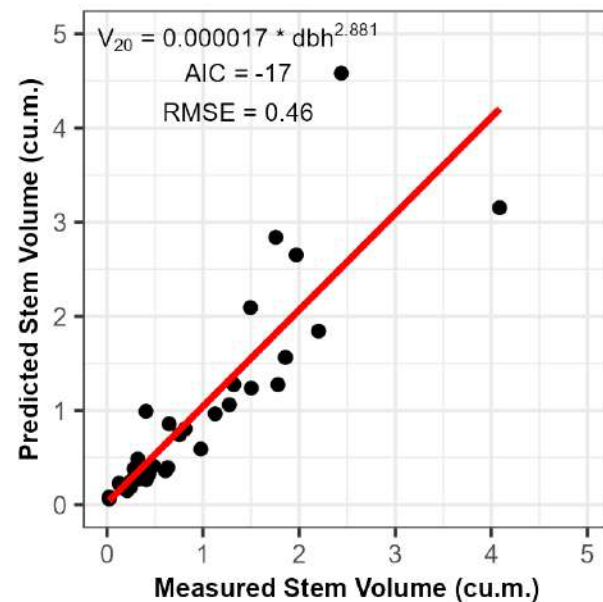
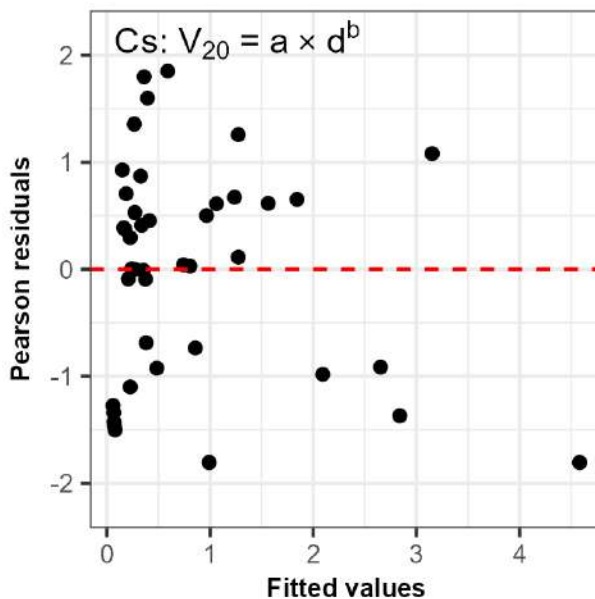
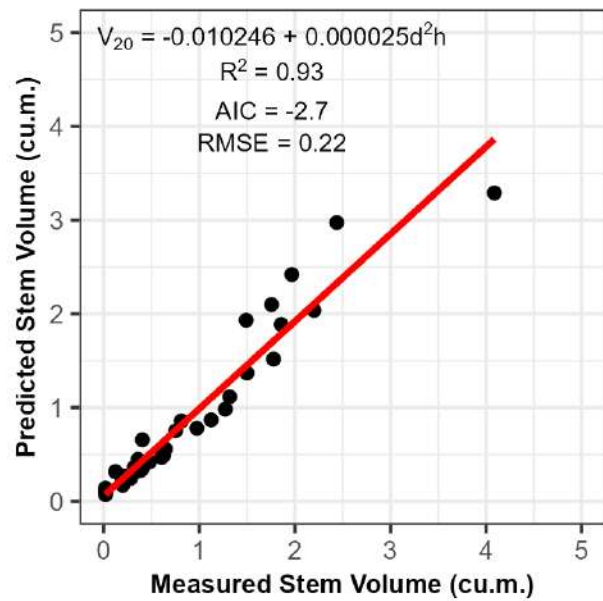
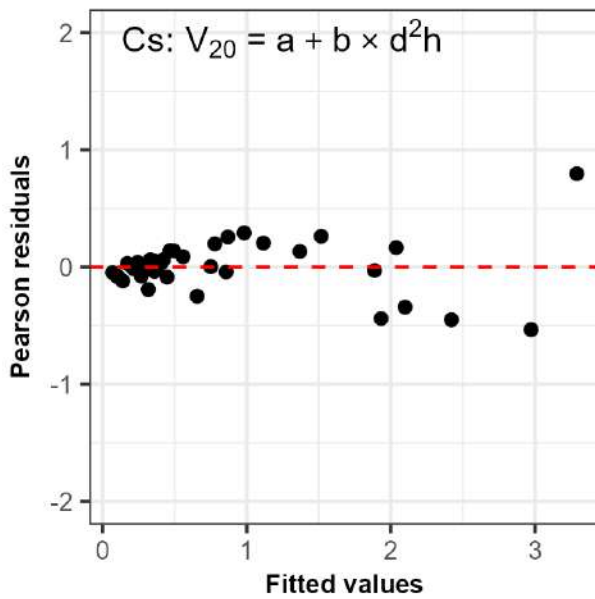
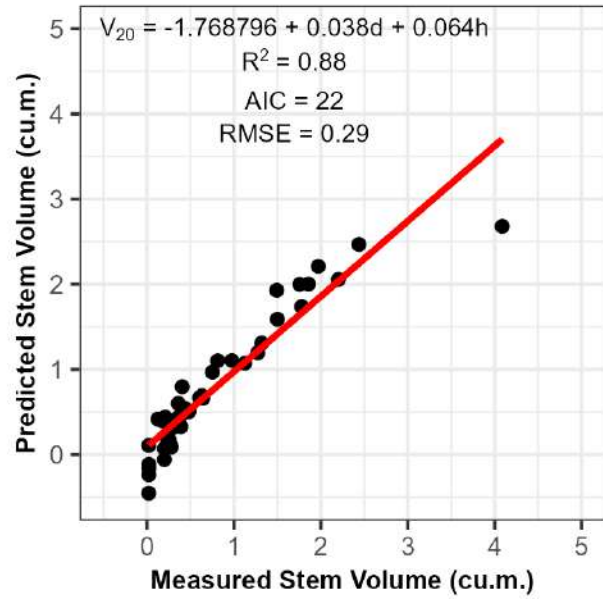
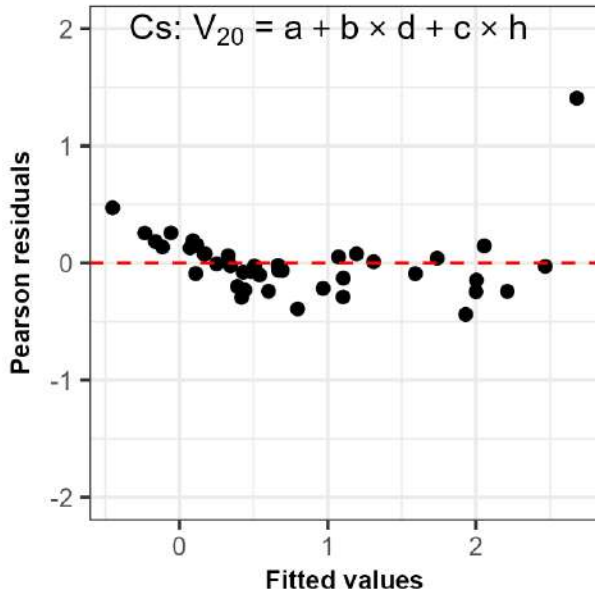


Figure A4.2: Left figures show the Pearsons residuals versus fitted values, indicating the distribution of errors, while right figures show the relationship between predicted versus the measured stem volume up to 20cm diameter of *Alnus nepalensis*. Models' performance is summarized by the equations, AIC, and RMSE for each model in the right figures. For tree code (An, Cs, Lp, Sw, Pr, Sr, Ta) refer Table 1.

Table A4.3: Summary of performance metrics for candidate models of *Castanopsis* spp, for volume (under bark) up to top 20cm. (All displayed parameters are significant at 5%).

Model	Equation	n	a	b	c	AIC	RMSE	R ²	MB
M1	$V = a + b * d$	42	-1.1168	0.051549	-	40.28	0.37	0.82	-
M2	$V = a + b * d + c * h$	42	-1.7688	0.038293	0.063936	21.96	0.29	0.89	-
M3	$V = a + b * d^2h$	42	-0.01025	0.000025	-	-2.74	0.22	0.94	-
M4	$V = a * d^b$	42	0.000017	2.880557	-	-17	0.46	-	-0.04
M5	$V = a * d^b * h^c$	42	0.000009	2.085137	1.221365	-25.7	0.21	-	-0.01
M6	$V = a * (d^2h)^b$	42	0.000009	1.089575	-	-33.5	0.23	-	-0.01





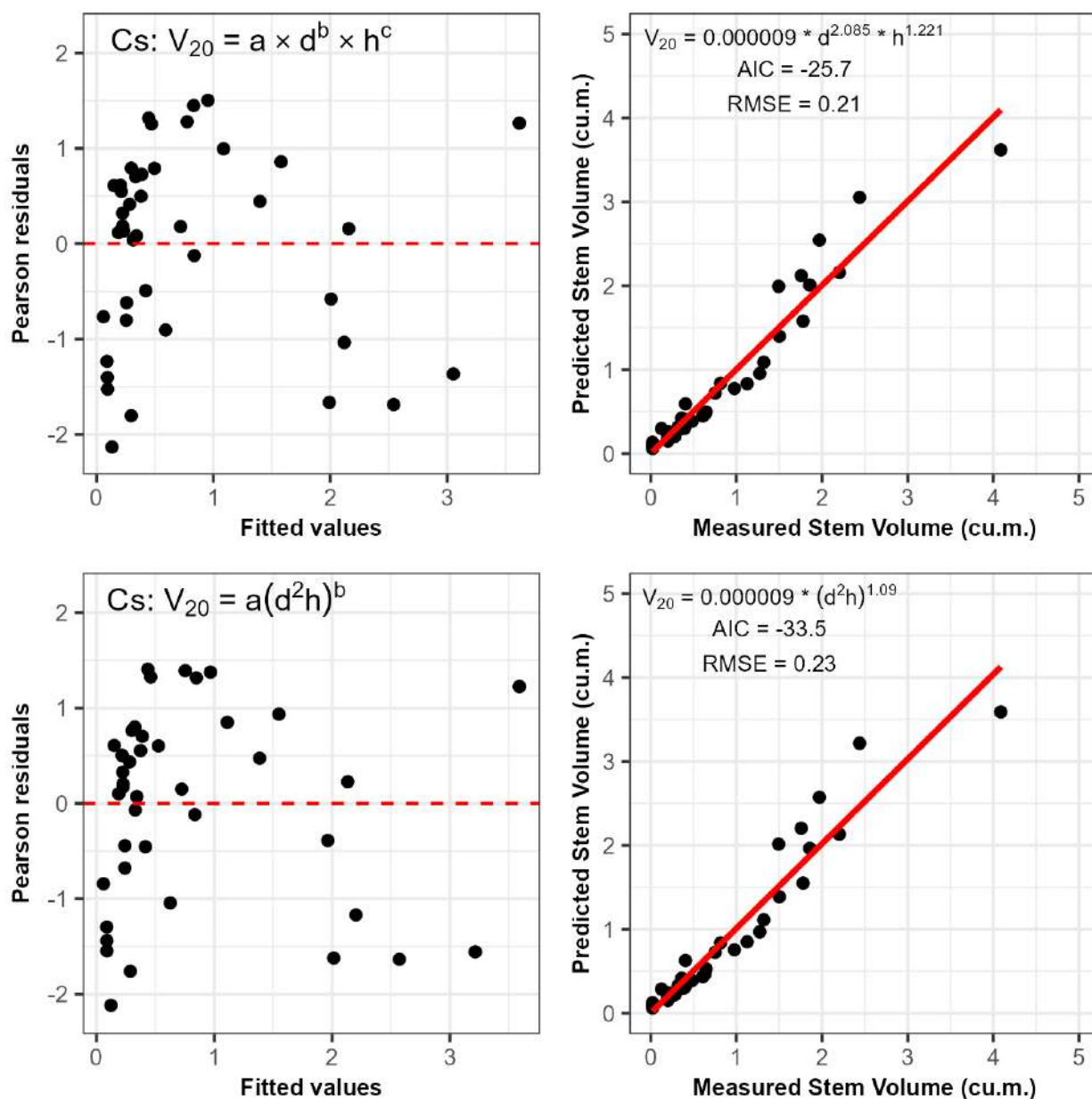
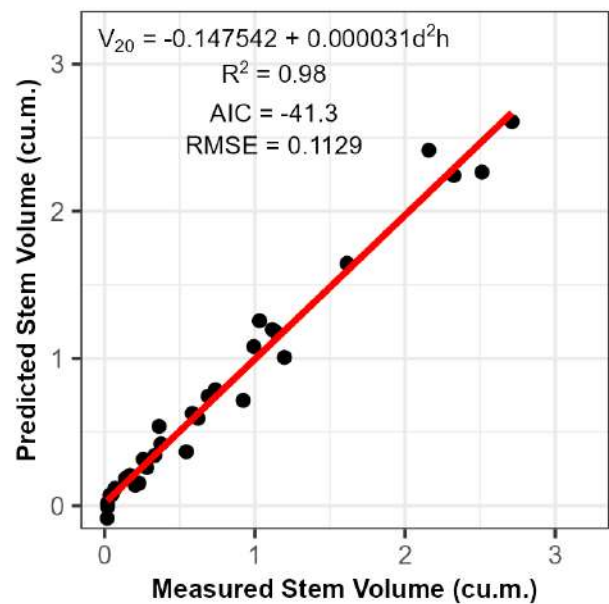
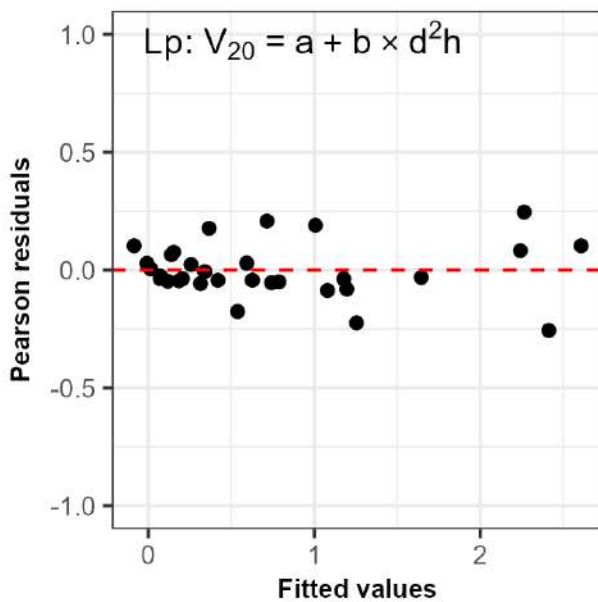
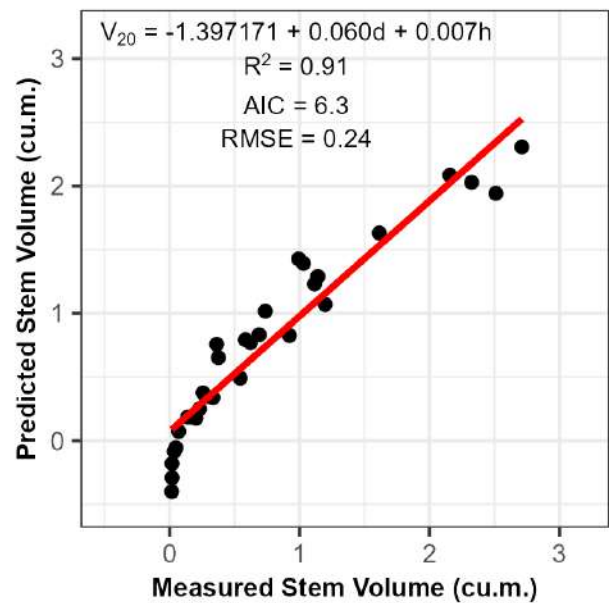
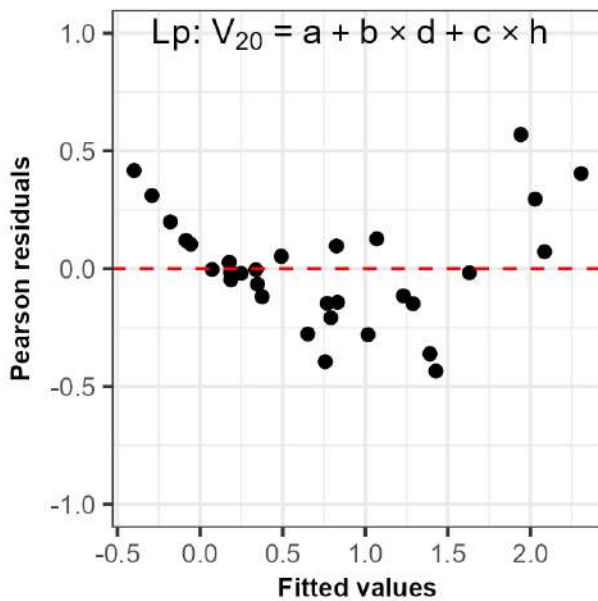
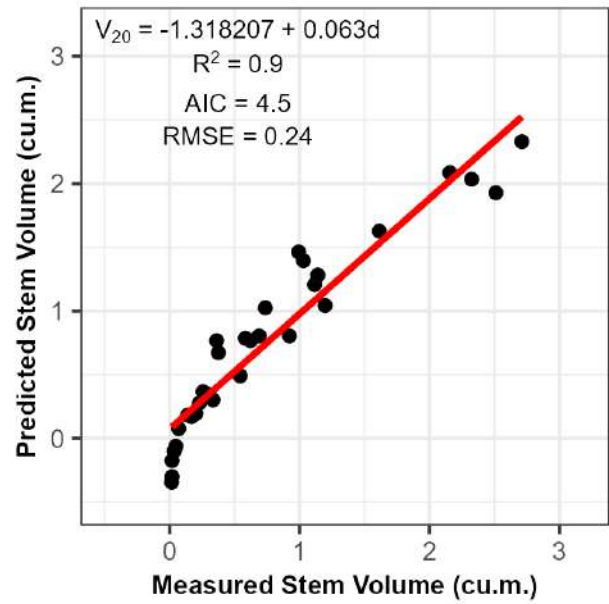
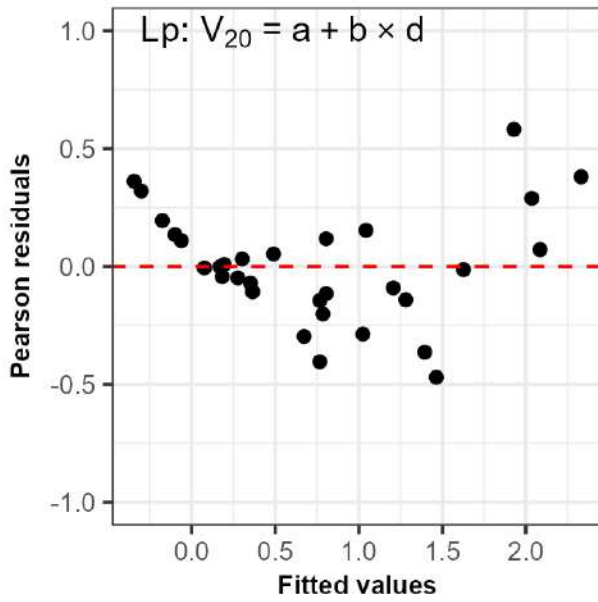


Figure A4.3: Left figures show the Pearsons residuals versus fitted values, indicating the distribution of errors, while right figures show the relationship between predicted versus the measured stem volume up to 20cm diameter of *Castanopsis* spp. Models' performance is summarized by the equations, AIC, and RMSE for each model in the right figures. For tree code (An, Cs, Lp, Sw, Pr, Sr, Ta) refer Table 1.

Table A4.4: Summary of performance metrics for candidate models of *Lagerstroemia parviflora* for volume (under bark) up to top 20cm. (All displayed parameters are significant at 5%).

Model	Equation	n	a	b	c	AIC	RMSE	R ²	MB
M1	$V = a + b * d$	31	-1.31821	0.062805	-	4.48	0.24	0.91	-
M2	$V = a + b * d + c * h$	31	-1.39717	0.060333	0.00749	6.28	0.24	0.91	-
M3	$V = a + b * d^2h$	31	-0.14754	0.000031	-	-41.26	0.12	0.98	-
M4	$V = a * d^b$	31	0.000008	3.185656	-	-24.8	0.18	-	-0.01
M5	$V = a * d^b * h^c$	31	0.000001	2.256694	1.660135	-32.9	0.11	-	-0.01
M6	$V = a * (d^2h)^b$	31	0.000002	1.231378	-	-39.3	0.12	-	-0.01



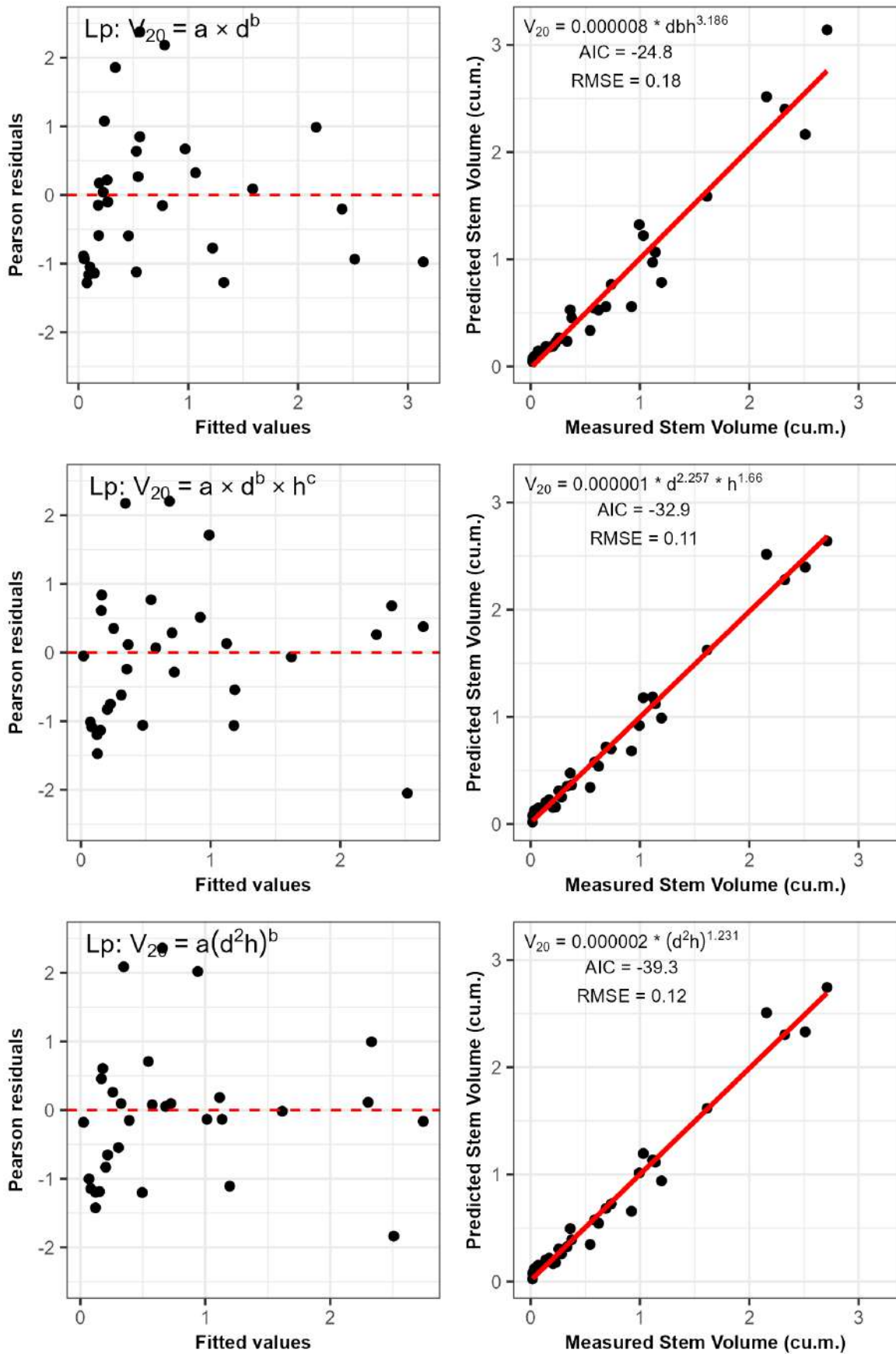
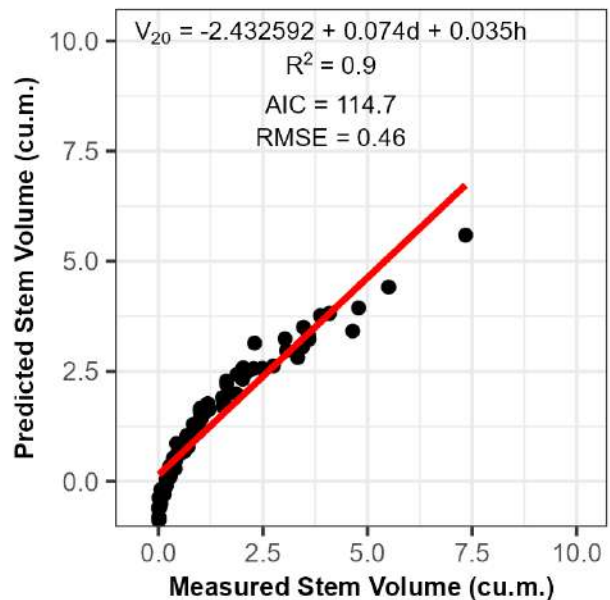
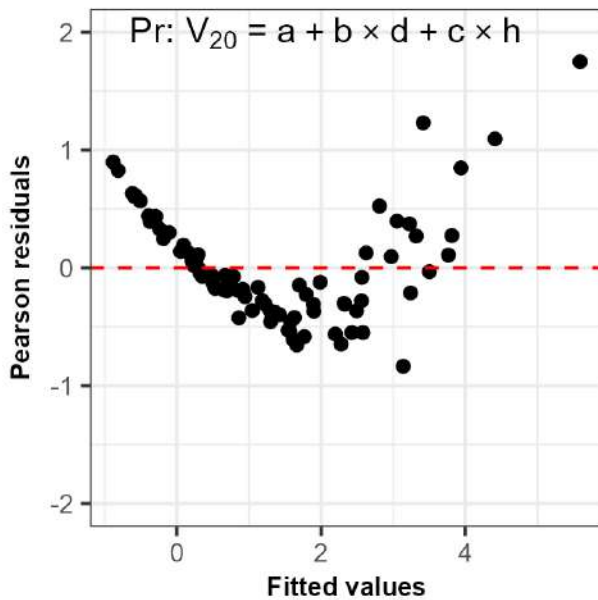
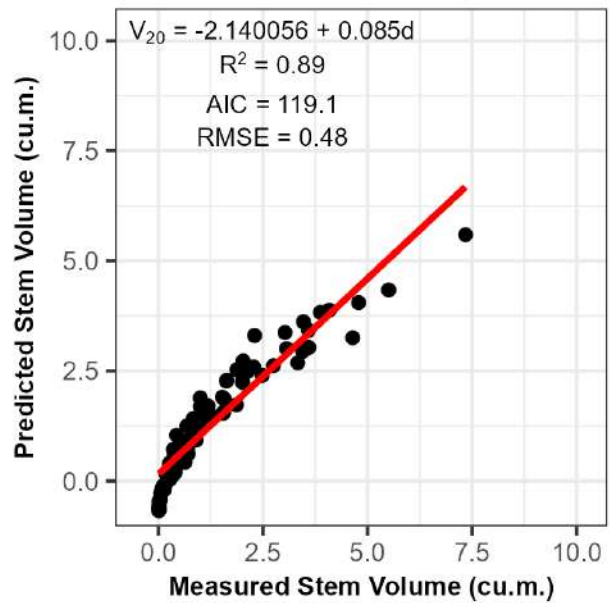
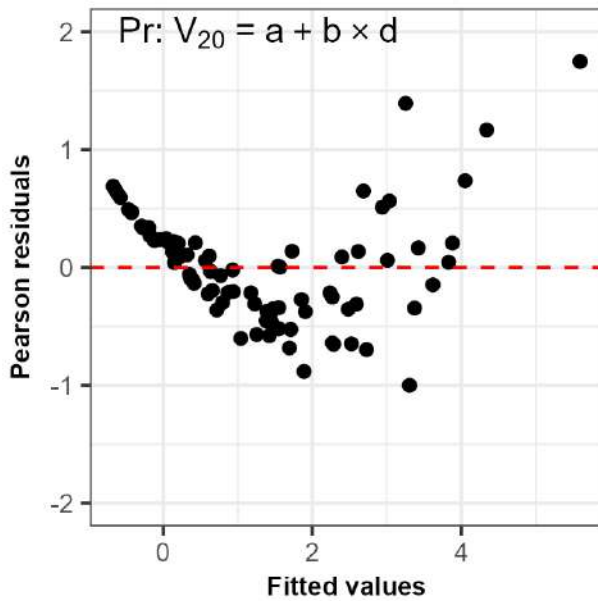
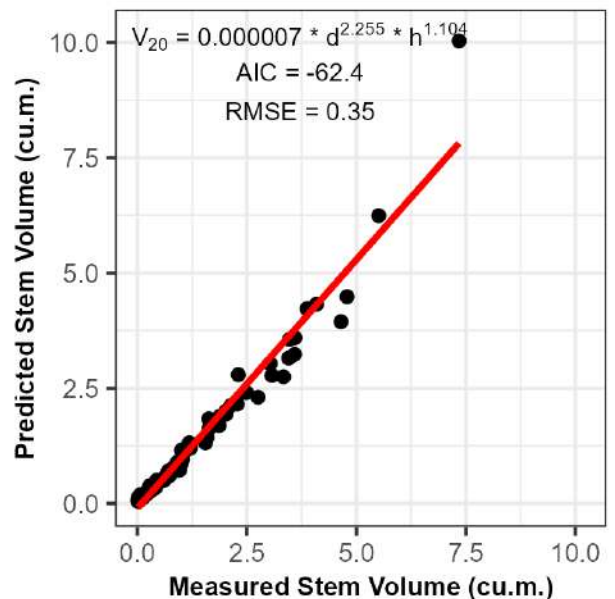
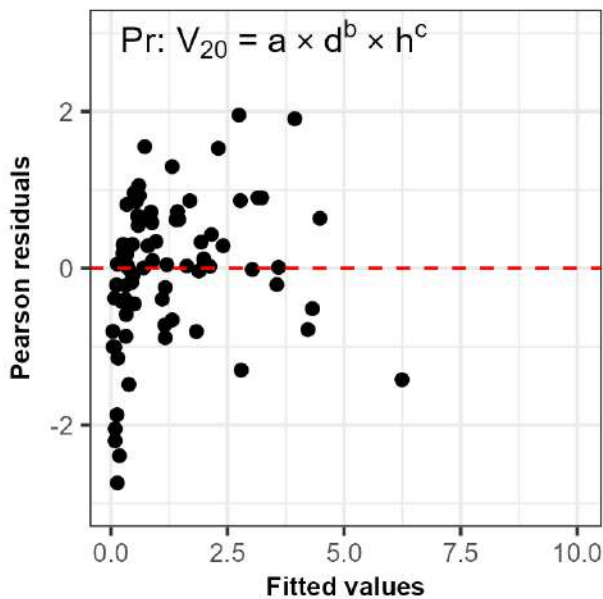
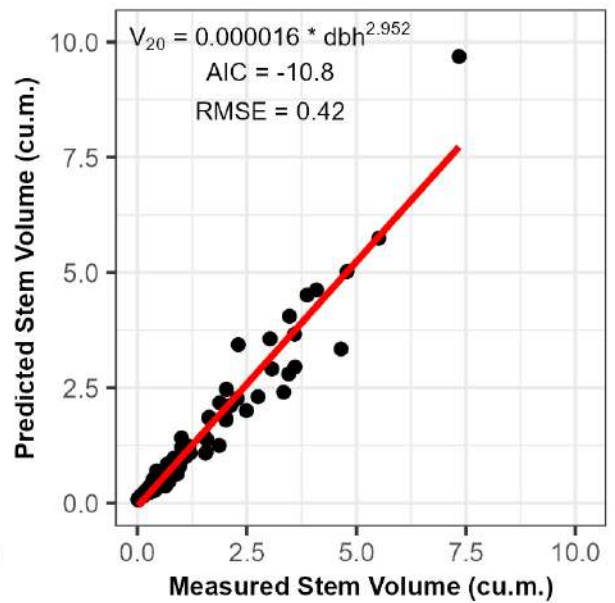
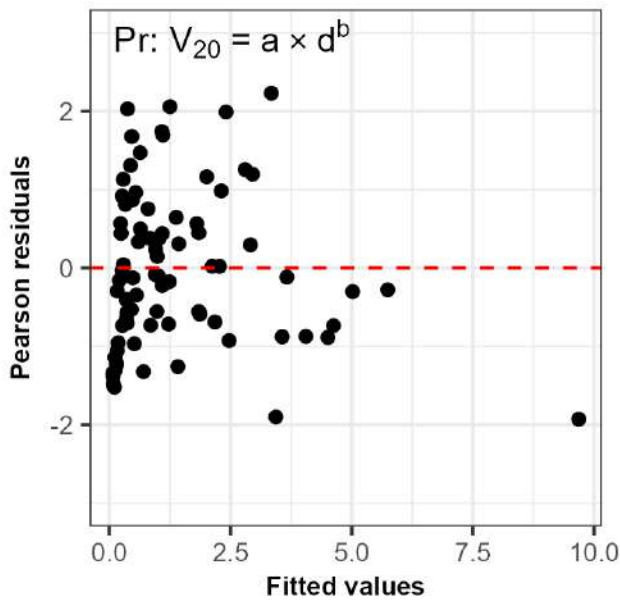
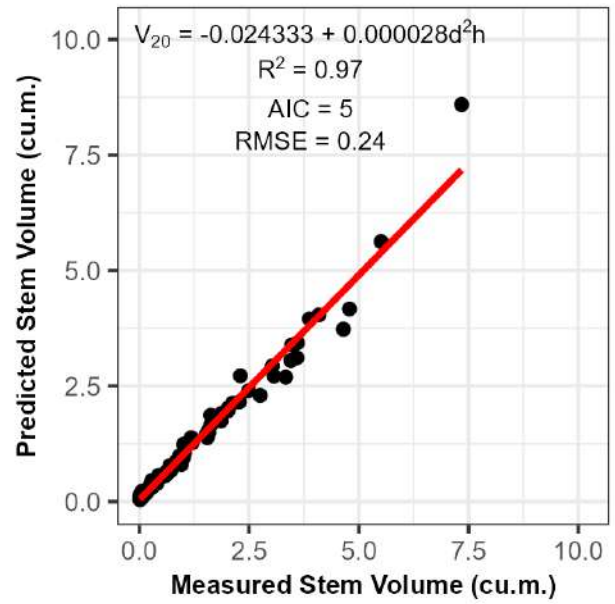
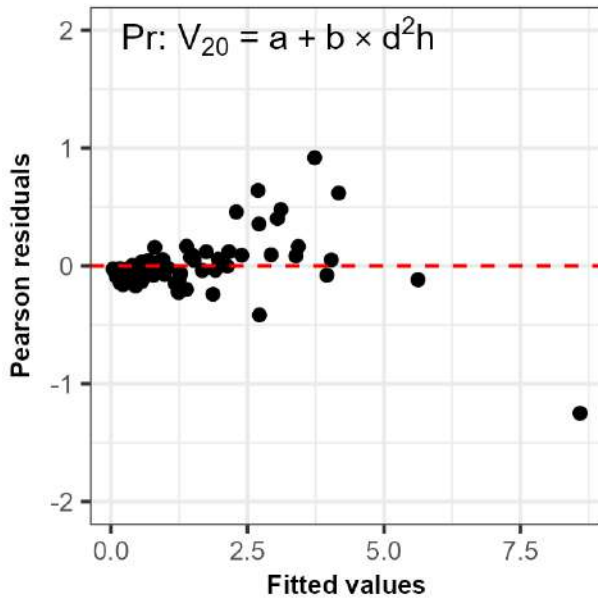


Figure A4.4: Left figures show the Pearsons residuals versus fitted values, indicating the distribution of errors, while right figures show the relationship between predicted versus the measured stem volume up to 20cm diameter of *Lagerstroemia parviflora*. Models' performance is summarized by the equations, AIC, and RMSE for each model in the right figures. For tree code (An, Cs, Lp, Sw, Pr, Sr, Ta) refer Table 1.

Table A4.5: Summary of performance metrics for candidate models of *Pinus roxburghii* for volume (under bark) up to top 20cm. (All displayed parameters are significant at 5%).

Model	Equation	n	a	b	c	AIC	RMSE	R ²	MB
M1	$V = a + b * d$	82	-2.14006	0.0848	-	119.06	0.49	0.89	-
M2	$V = a + b * d + c * h$	82	-2.43259	0.074097	0.034807	114.71	0.47	0.9	-
M3	$V = a + b * d^2h$	82	-0.02433	0.000028	-	5.02	0.25	0.98	-
M4	$V = a * d^b$	82	0.000016	2.951888	-	-10.8	0.42	-	-0.02
M5	$V = a * d^b * h^c$	82	0.000007	2.254578	1.104038	-62.4	0.35	-	-0.01
M6	$V = a * (d^2h)^b$	82	0.000007	1.12172	-	-70.4	0.35	-	-0.01





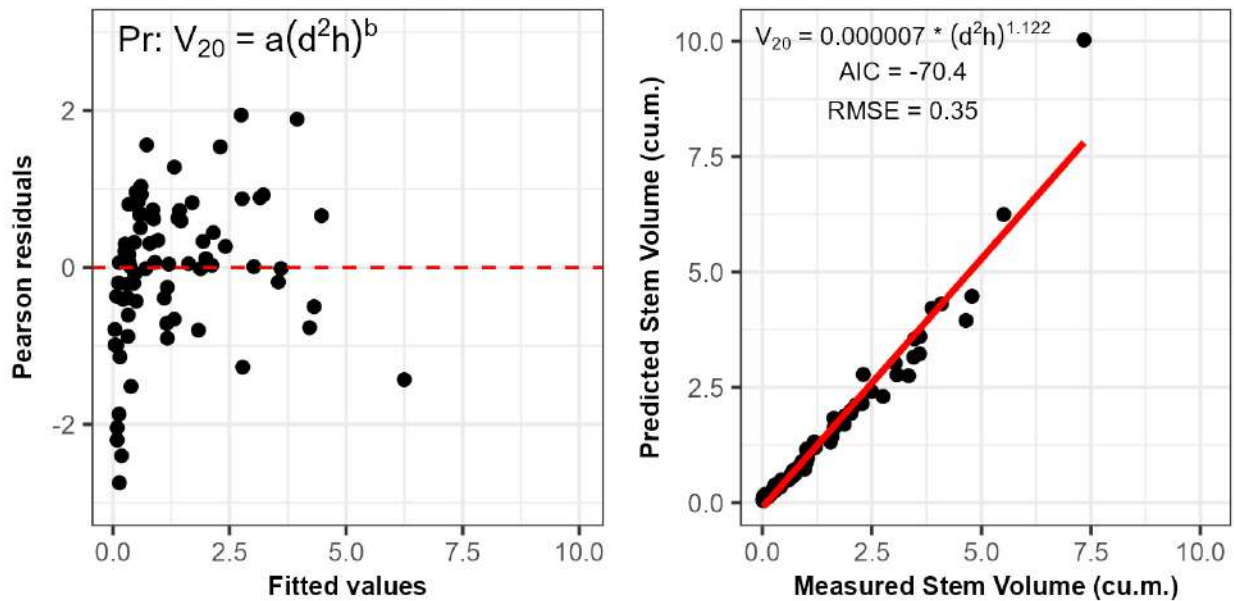
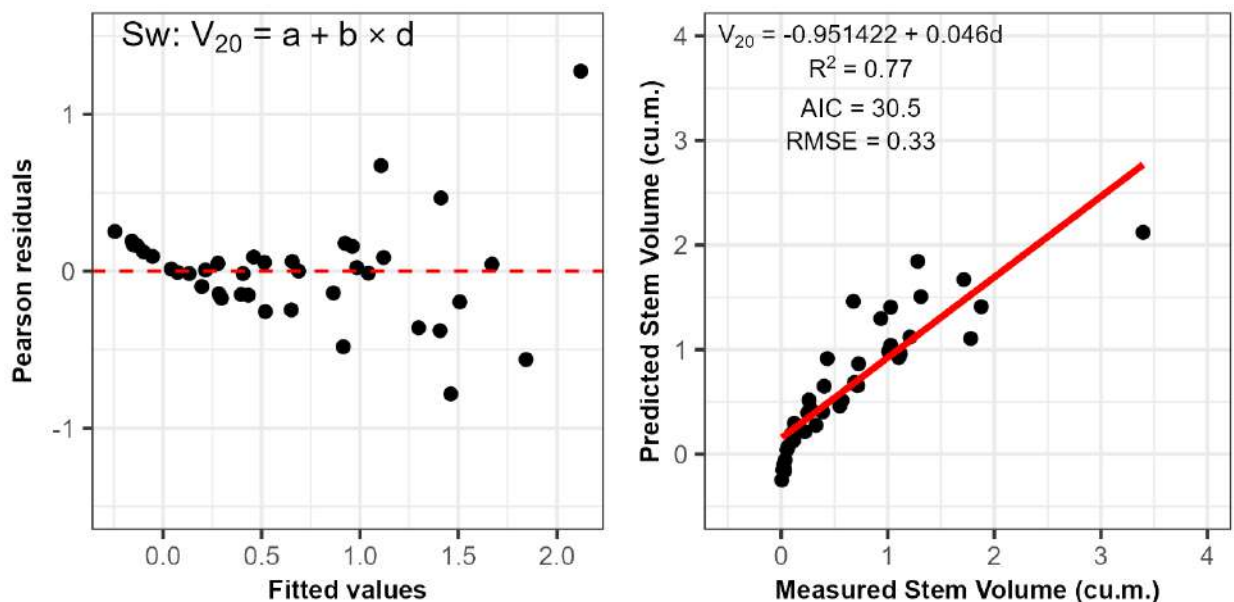


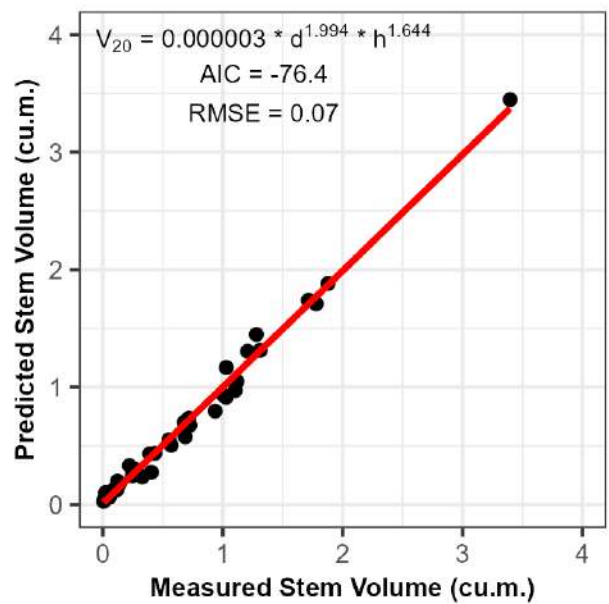
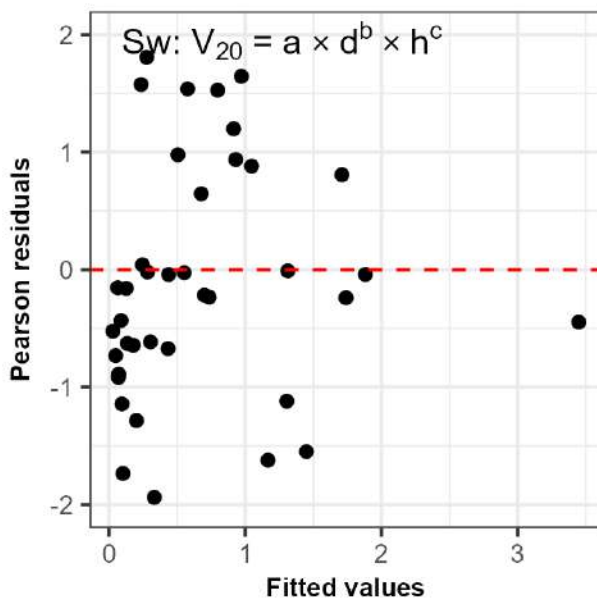
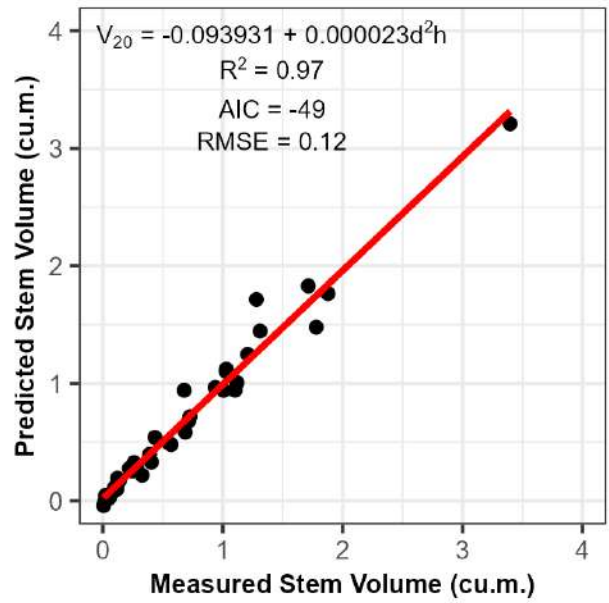
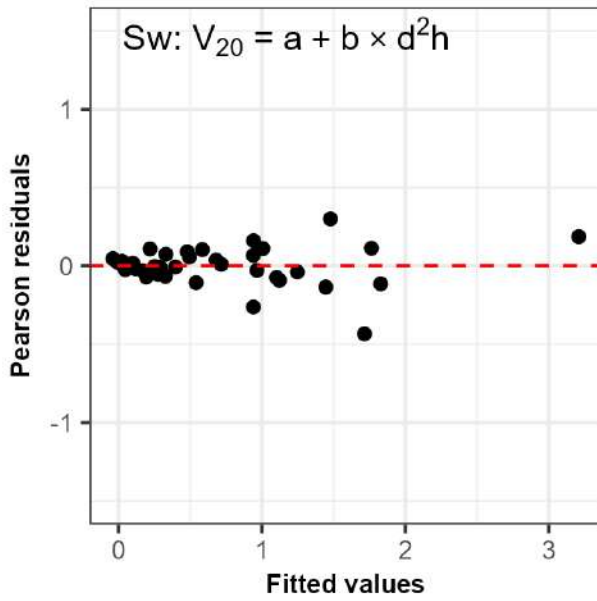
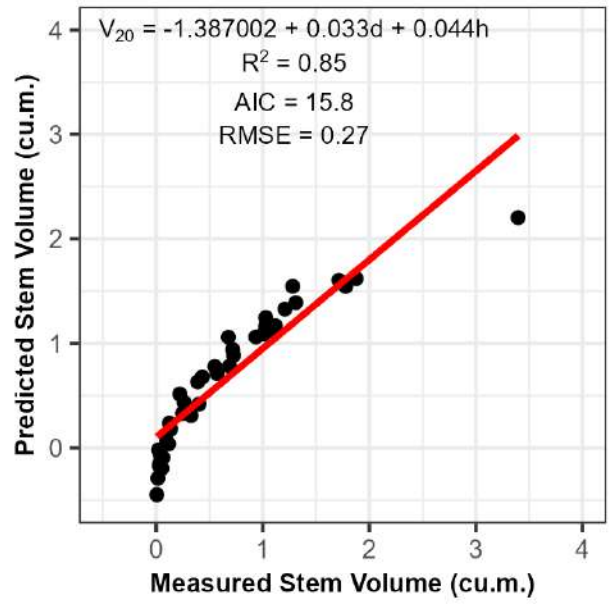
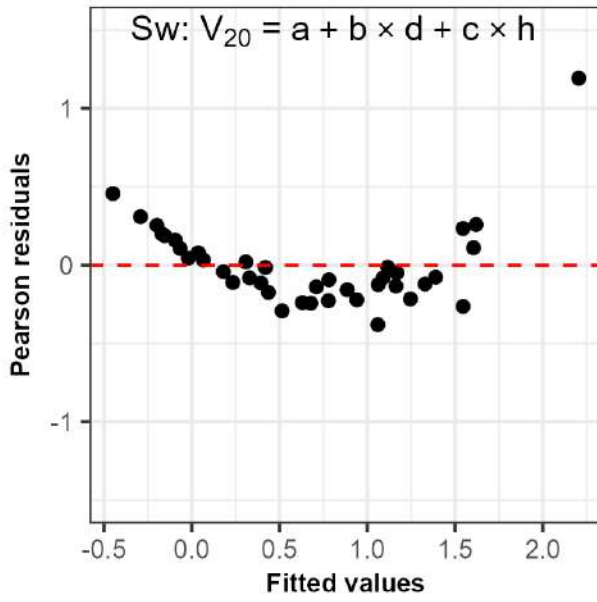
Figure A4.5: Left figures show the Pearsons residuals versus fitted values, indicating the distribution of errors, while right figures show the relationship between predicted versus the measured stem volume up to 20cm diameter of *Pinus roxburghii*. Models' performance is summarized by the equations, AIC, and RMSE for each model in the right figures. For tree code (An, Cs, Lp, Sw, Pr, Sr, Ta) refer Table 1.

Table A4.6: Summary of performance metrics for candidate models of *Schima wallichii* for volume (under bark) up to top 20cm. (All displayed parameters are significant at 5%).

Model	Equation	n	a	b	c	AIC	RMSE	R ²	MB
M1	$V = a + b * d$	39	-0.95142	0.045521	-	30.55	0.34	0.78	-
M2	$V = a + b * d + c * h$	39	-1.387	0.03325	0.043577	15.85	0.27	0.86	-
M3	$V = a + b * d^2h$	39	-0.09393	0.000023	-	-49.01	0.12	0.98	-
M4	$V = a * d^b$	39	*	*	-	-	-	-	-
M5	$V = a * d^b * h^c$	39	0.000003	1.994043	1.644049	-76.4	0.07	-	-0.01
M6	$V = a * (d^2h)^b$	39	0.000002	1.221542	-	-66.9	0.14	-	-0.03

Note: * refers parameter not significant





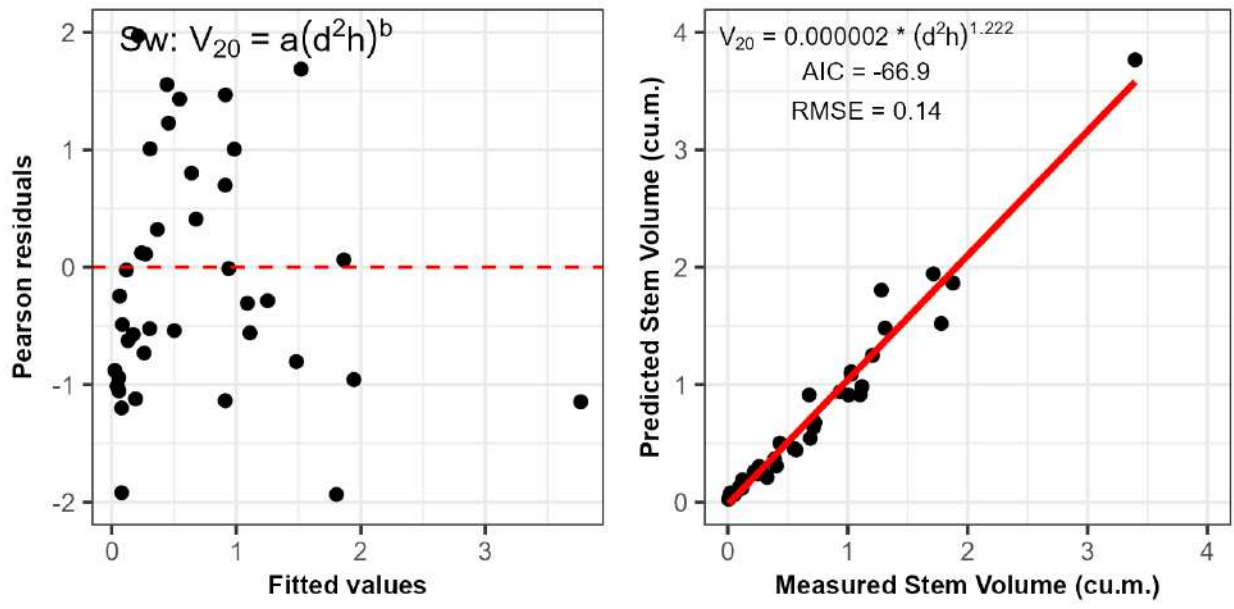
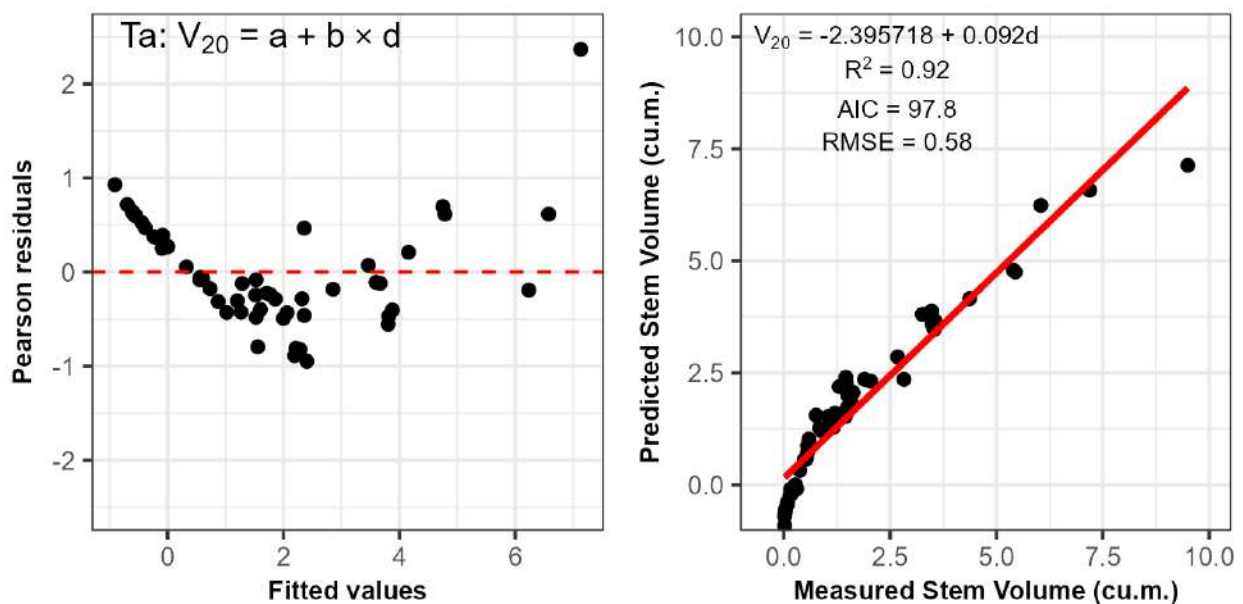


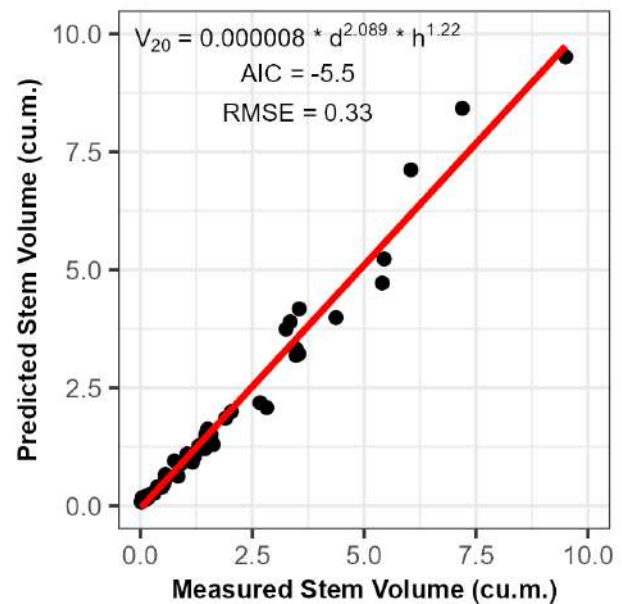
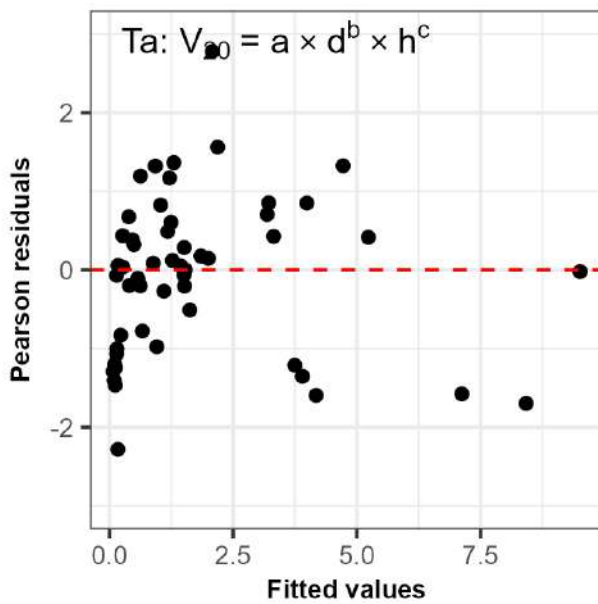
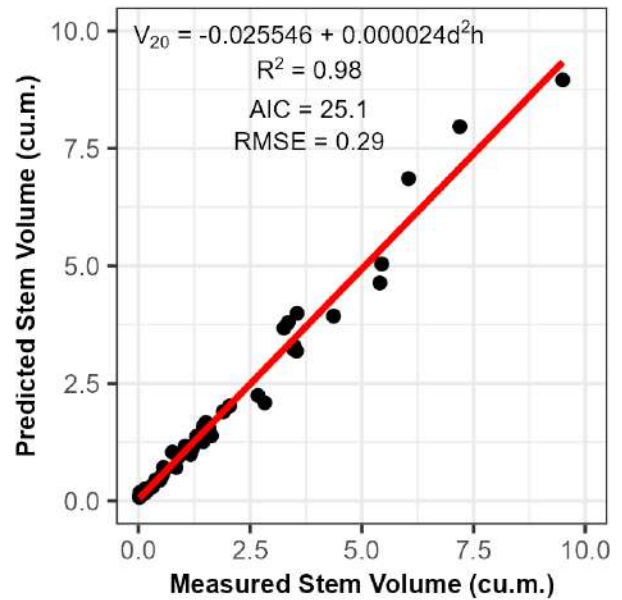
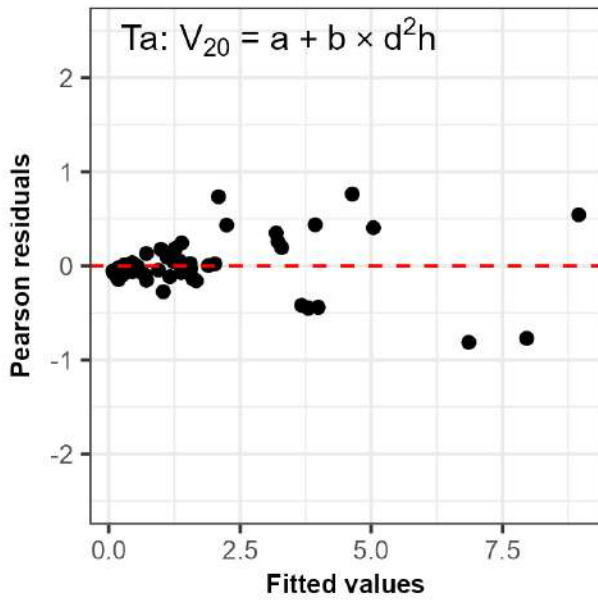
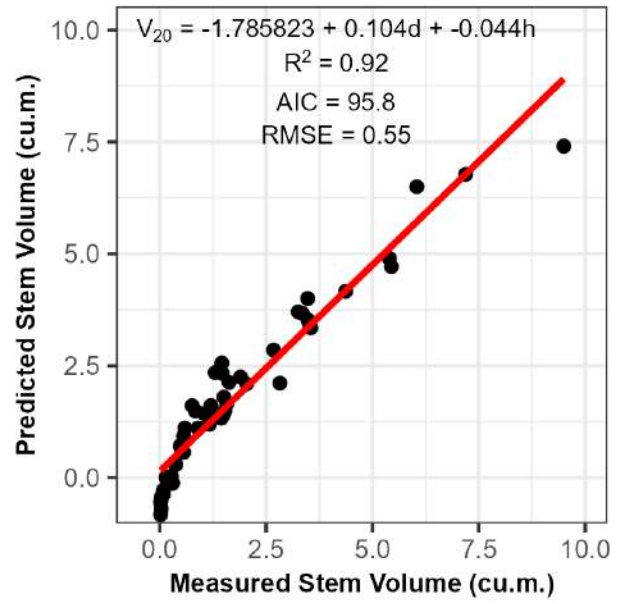
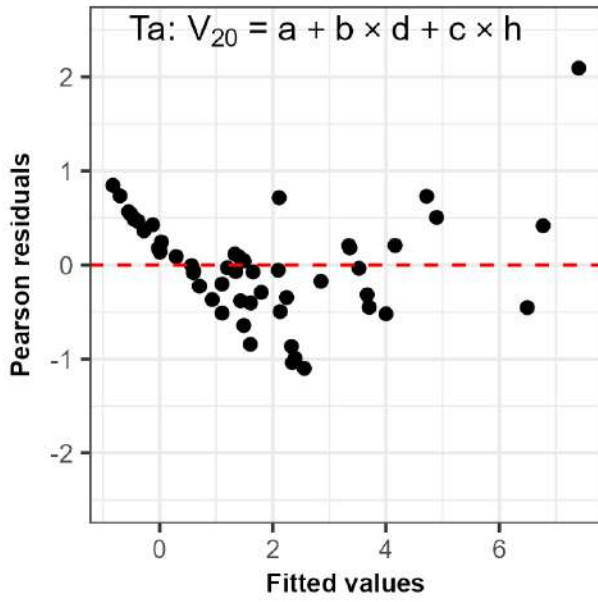
Figure A4.6: Left figures show the Pearsons residuals versus fitted values, indicating the distribution of errors, while right figures show the relationship between predicted versus the measured stem volume up to 20cm diameter of *Schima wallichii*. Models' performance is summarized by the equations, AIC, and RMSE for each model in the right figures. For tree code (An, Cs, Lp, Sw, Pr, Sr, Ta) refer Table 1.

Table A4.7: Summary of performance metrics for candidate models of *Terminalia alata* for volume (under bark) up to top 20cm. (All displayed parameters are significant at 5%).

Model	Equation	n	a	b	c	AIC	RMSE	R ²	MB
M1	$V = a + b * d$	53	-2.39572	0.092314	-	97.76	0.58	0.92	-
M2	$V = a + b * d + c * h$	53	-1.78582	0.104041	-0.04446	95.81	0.56	0.93	-
M3	$V = a + b * d^2h$	53	-0.02555	0.000024	-	25.1	0.29	0.98	-
M4	$V = a * d^b$	53	*	*	-	-	-	-	-
M5	$V = a * d^b * h^c$	53	0.000008	2.089407	1.219993	-5.5	0.33	-	-0.01
M6	$V = a * (d^2h)^b$	53	0.00001	1.074116	-	-12.9	0.34	-	-0.01

Note: * refers parameter not significant





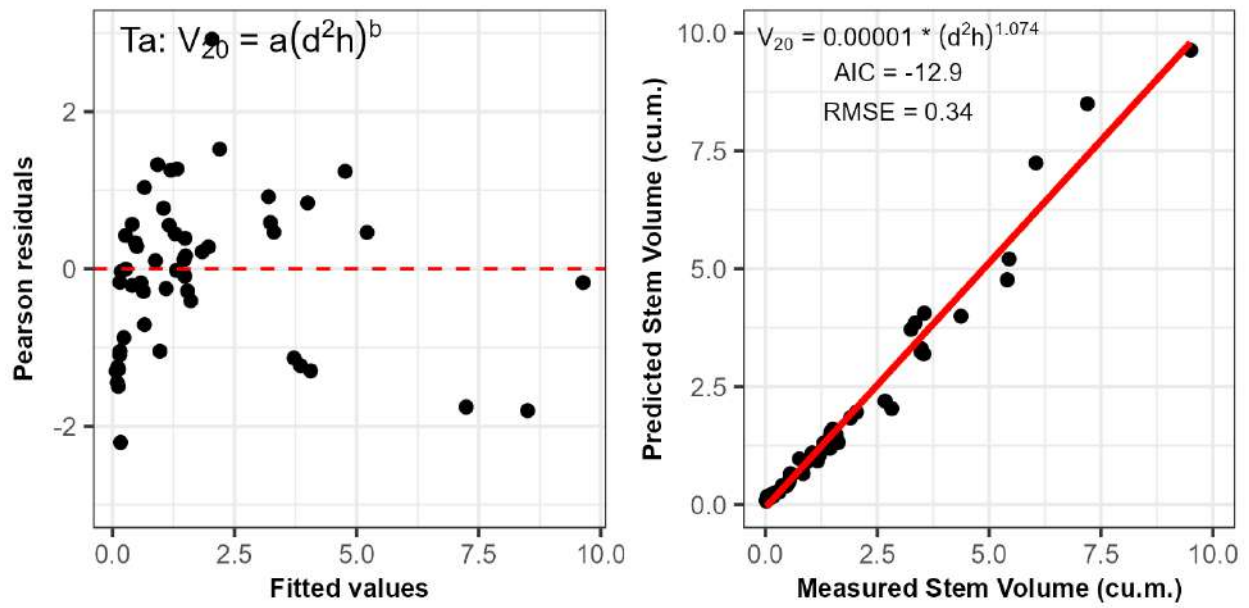


Figure A4.7: Left figures show the Pearsons residuals versus fitted values, indicating the distribution of errors, while right figures show the relationship between predicted versus the measured stem volume up to 20cm diameter of *Terminalia alata*. Models' performance is summarized by the equations, AIC, and RMSE for each model in the right figures. For tree code (An, Cs, Lp, Sw, Pr, Sr, Ta) refer Table 1.

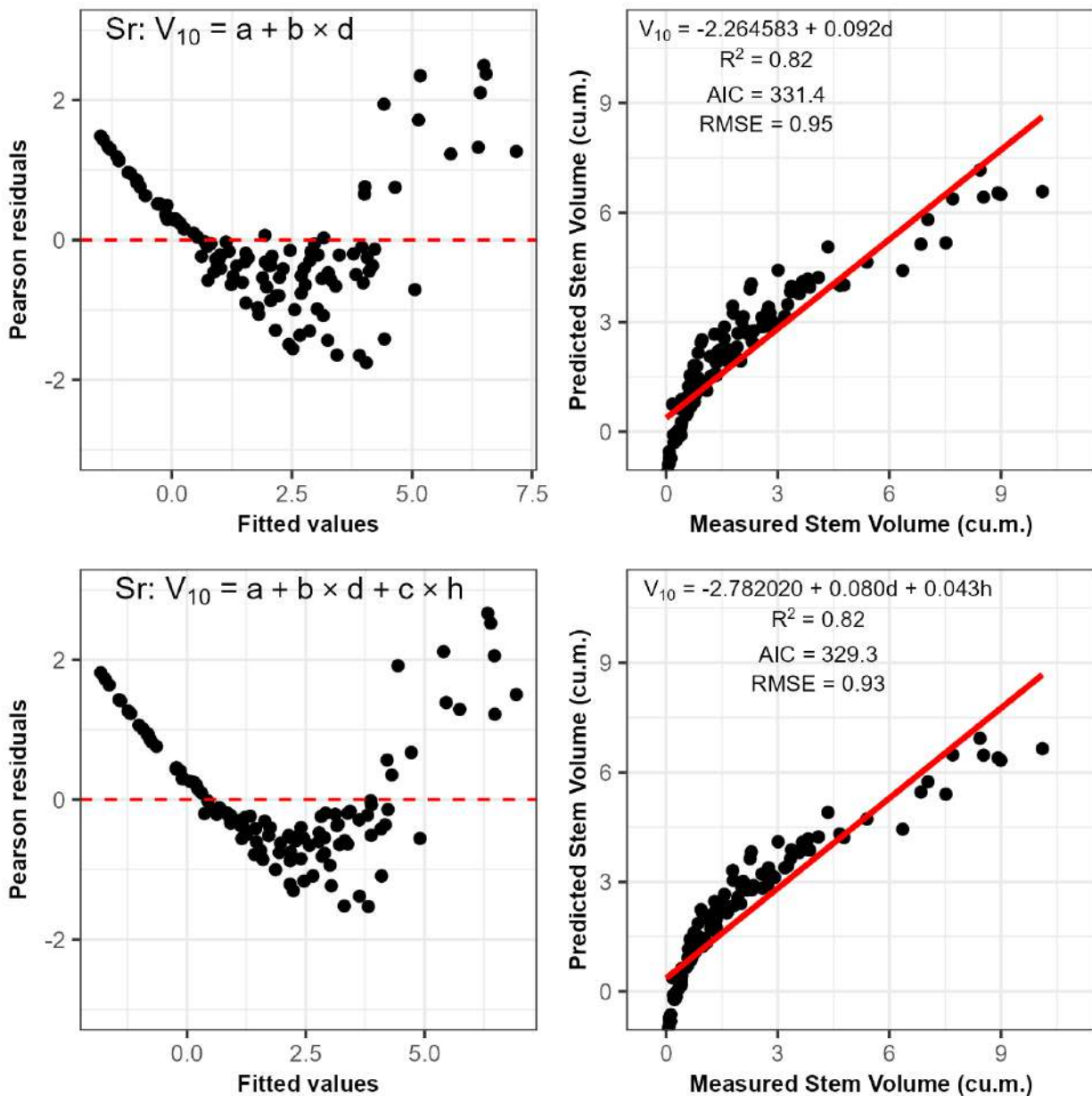
Annex V

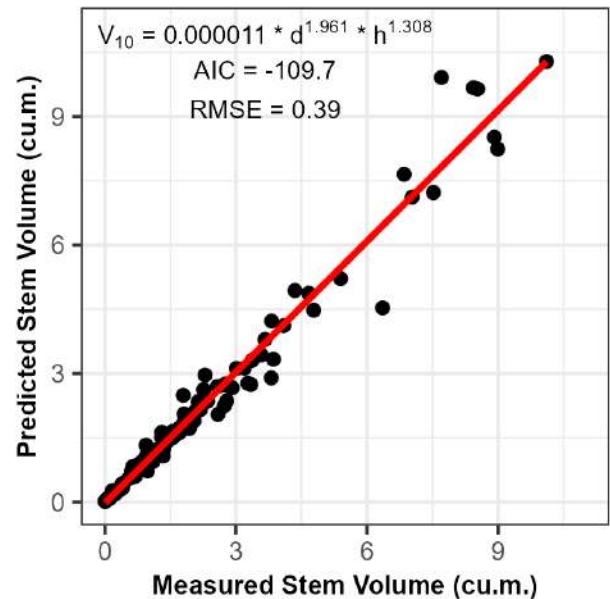
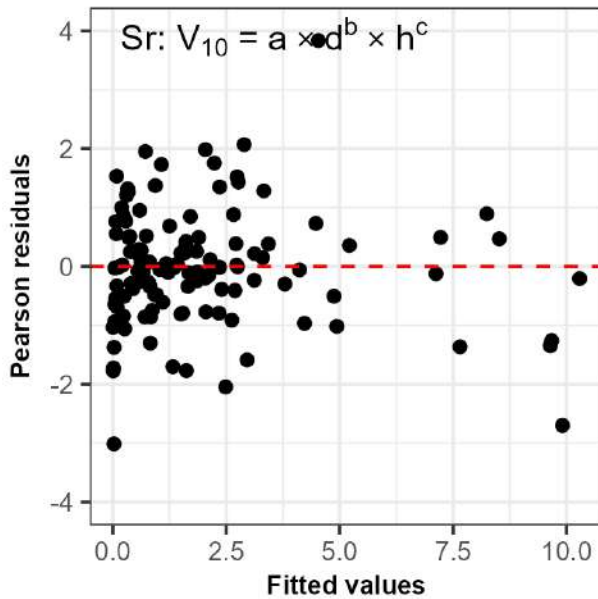
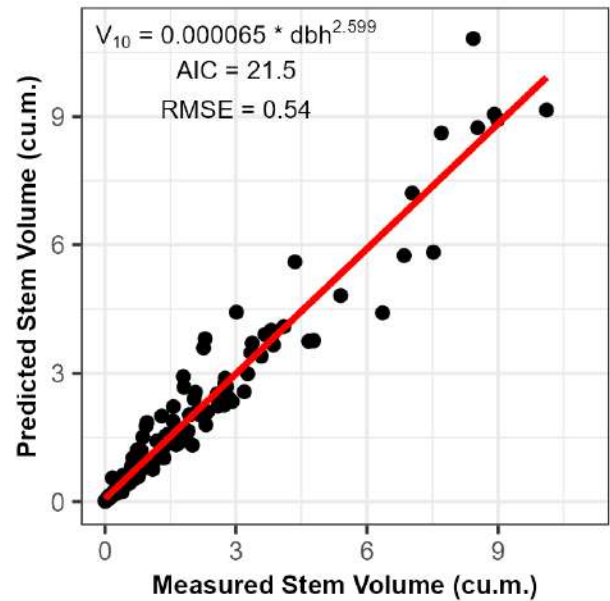
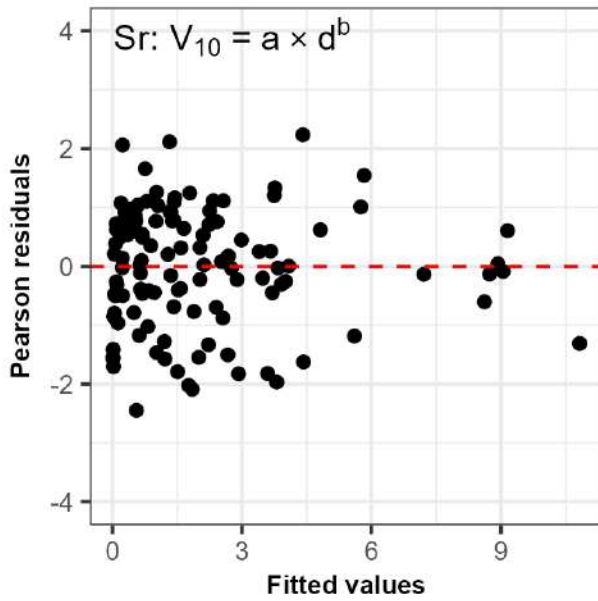
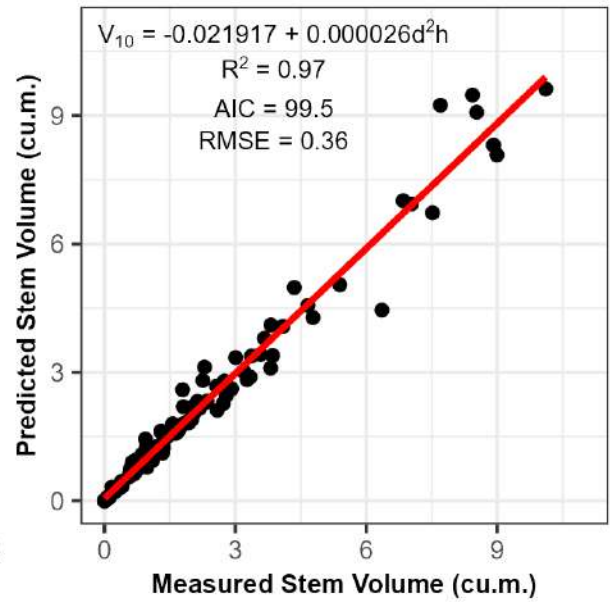
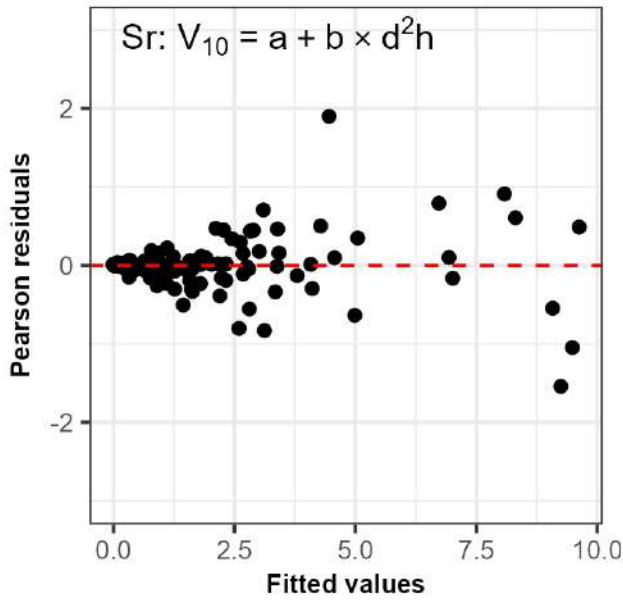
Volume under bark up to top 10cm diameter

Table A5.1 Summary of performance metrics for candidate models of *Shorea robusta* for volume (under bark) up to top 10cm. (All displayed parameters are significant at 5%).

Model	Equation	n	a	b	c	AIC	RMSE	R ²	MB
M1	$V = a + b * d$	119	-2.26458	0.092122	-	331.37	0.82	0.95	-
M2	$V = a + b * d + c * h$	119	-2.78202	0.080343	0.042577	329.32	0.83	0.94	-
M3	$V = a + b * d^2h$	119	-0.02192	0.000026	-	99.5	0.98	0.36	-
M4	$V = a * d^b$	119	0.000065	2.598779	-	21.5	-	0.54	-0.02
M5	$V = a * d^b * h^c$	119	0.000011	1.960877	1.30819	-109.7	-	0.39	-0.02
M6	$V = a * (d^2h)^b$	119	0.000015	1.045663	-	-108.2	-	0.38	-0.03

Note: * refers parameter not significant





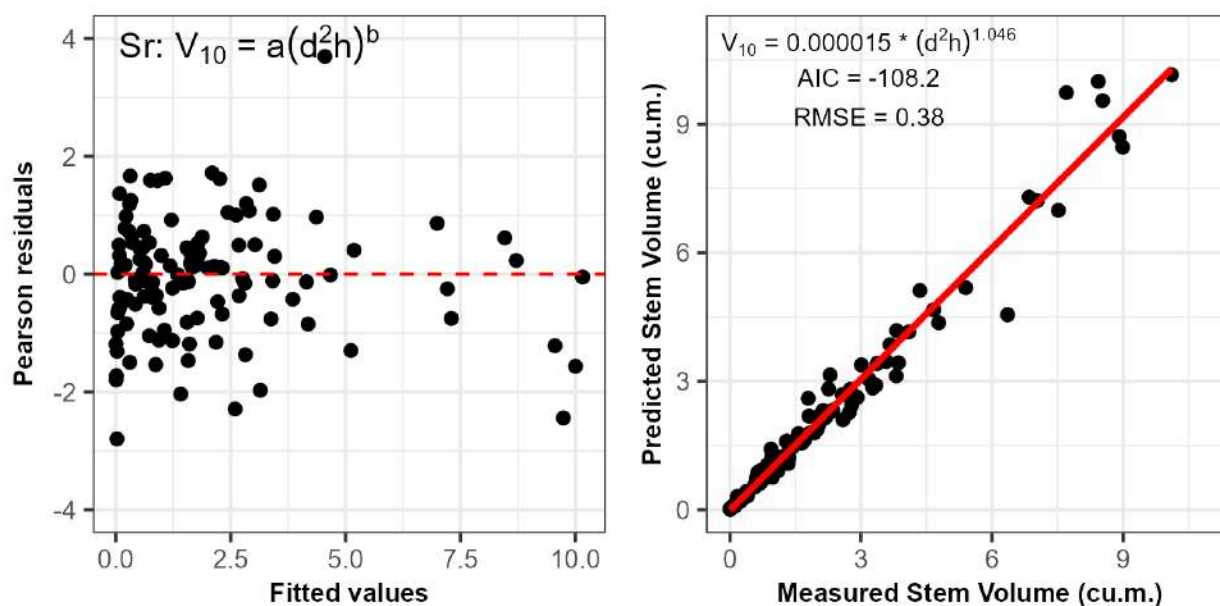
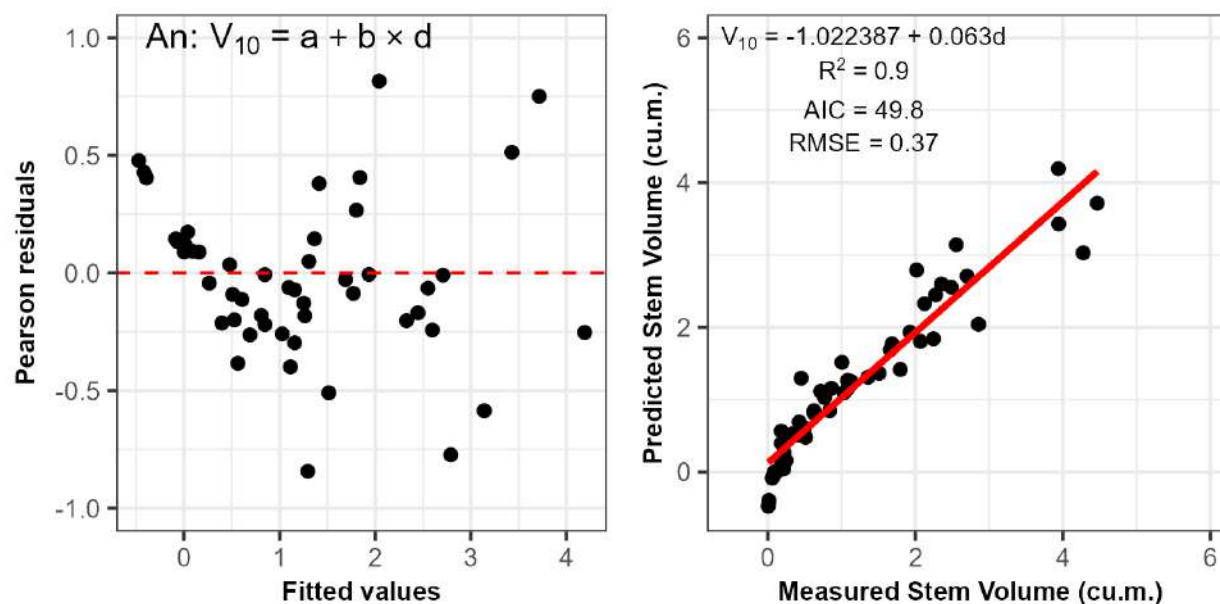


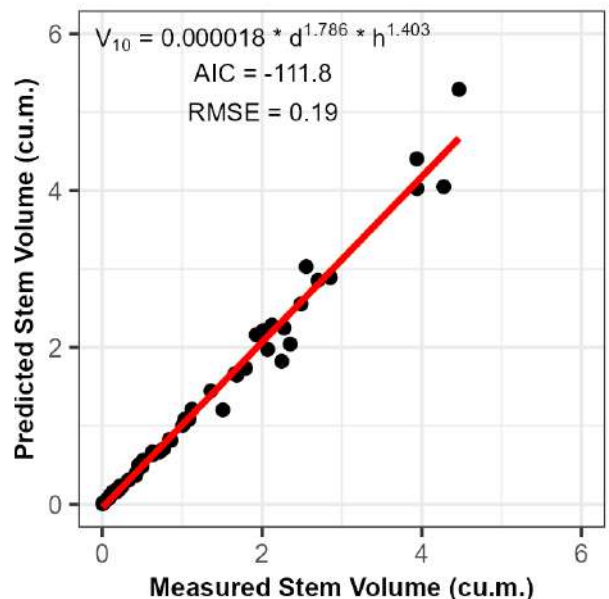
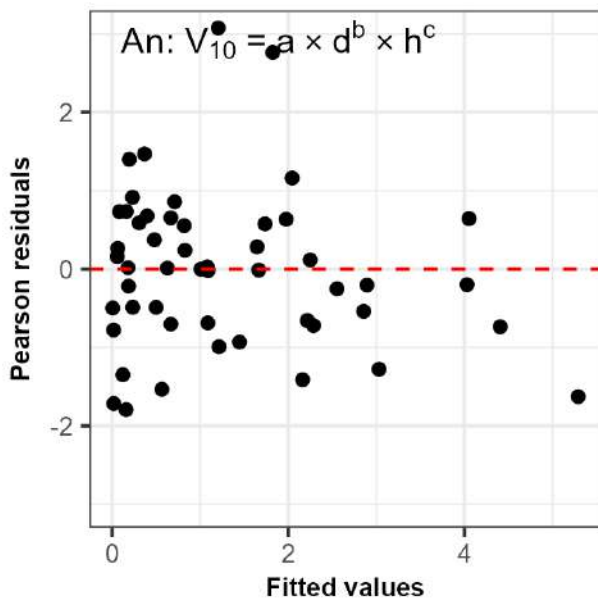
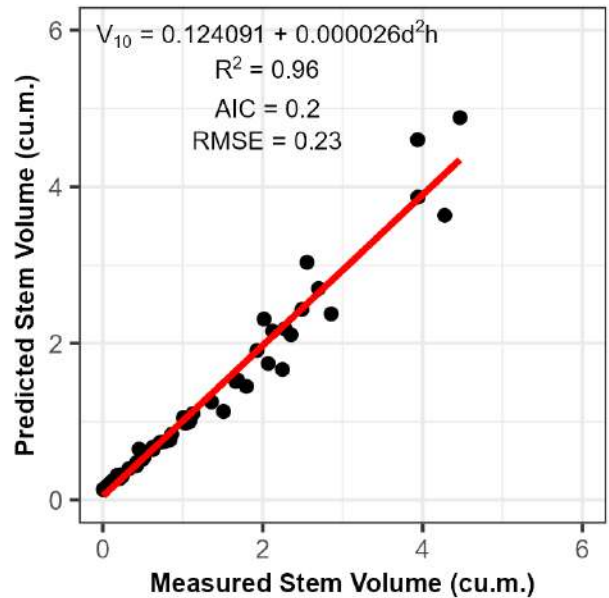
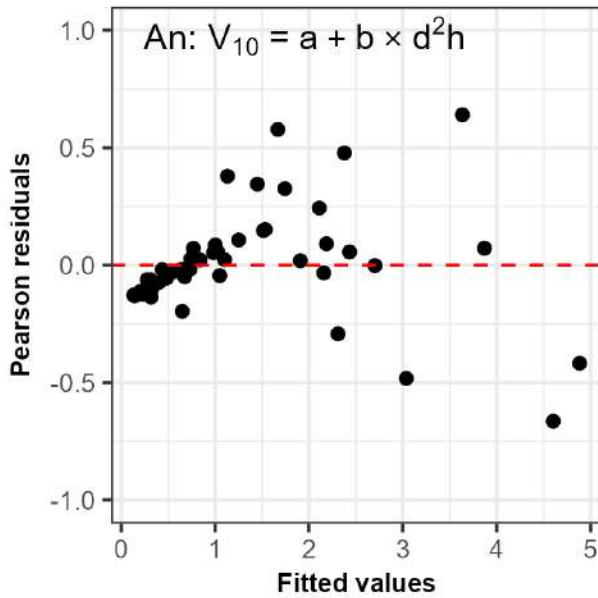
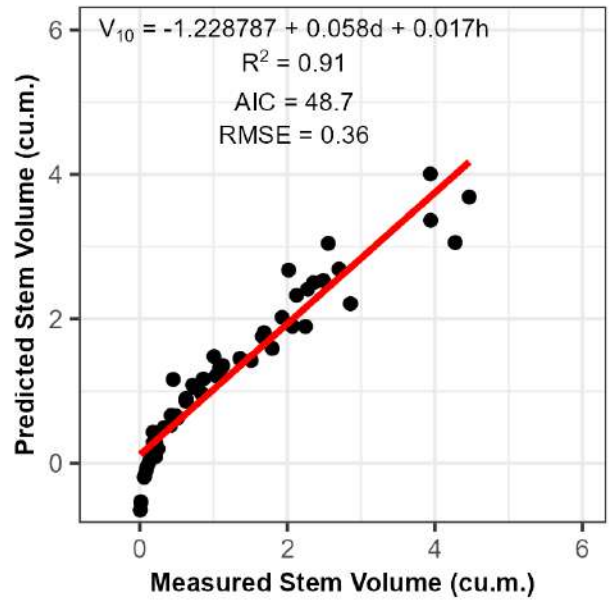
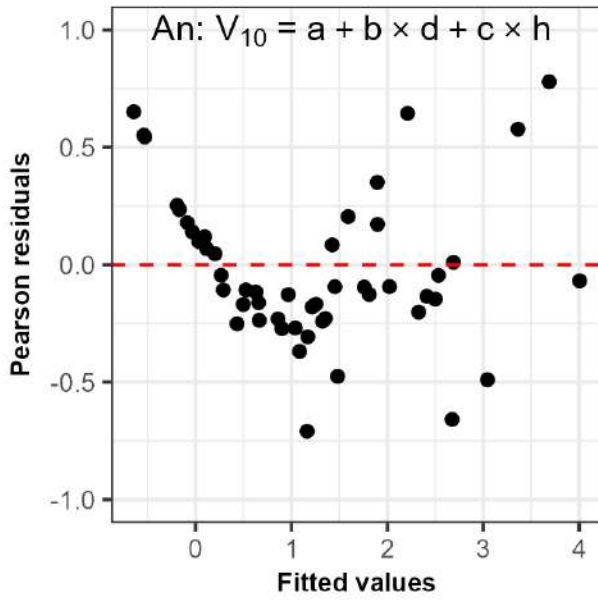
Figure A5.2: Left figures show the Pearsons residuals versus fitted values, indicating the distribution of errors, while right figures show the relationship between predicted versus the measured stem volume up to 10cm diameter of *Alnus nepalensis*. Models' performance is summarized by the equations, AIC, and RMSE for each model in the right figures. For tree code (An, Cs, Lp, Sw, Pr, Sr, Ta) refer Table 1.

Table A5.3: Summary of performance metrics for candidate models of *Castanopsis* spp. for volume (under bark) up to top 10cm. (All displayed parameters are significant at 5%).

Model	Equation	n	a	b	c	AIC	RMSE	R ²	MB
M1	$V = a + b * d$	51	-1.02239	0.0625	-	49.81	0.91	0.38	-
M2	$V = a + b * d + c * h$	51	-1.22879	0.057743	0.016694	48.69	0.91	0.37	-
M3	$V = a + b * d^2h$	51	0.124091	0.000026	-	0.16	0.97	0.23	-
M4	$V = a * d^b$	51	*	*	-	-	-	-	-
M5	$V = a * d^b * h^c$	51	0.000018	1.785698	1.403011	-111.8	-	0.19	-0.03
M6	$V = a * (d^2h)^b$	51	0.000029	1.004311	-	-90.8	-	0.33	-0.09

Note: * refers parameter not significant





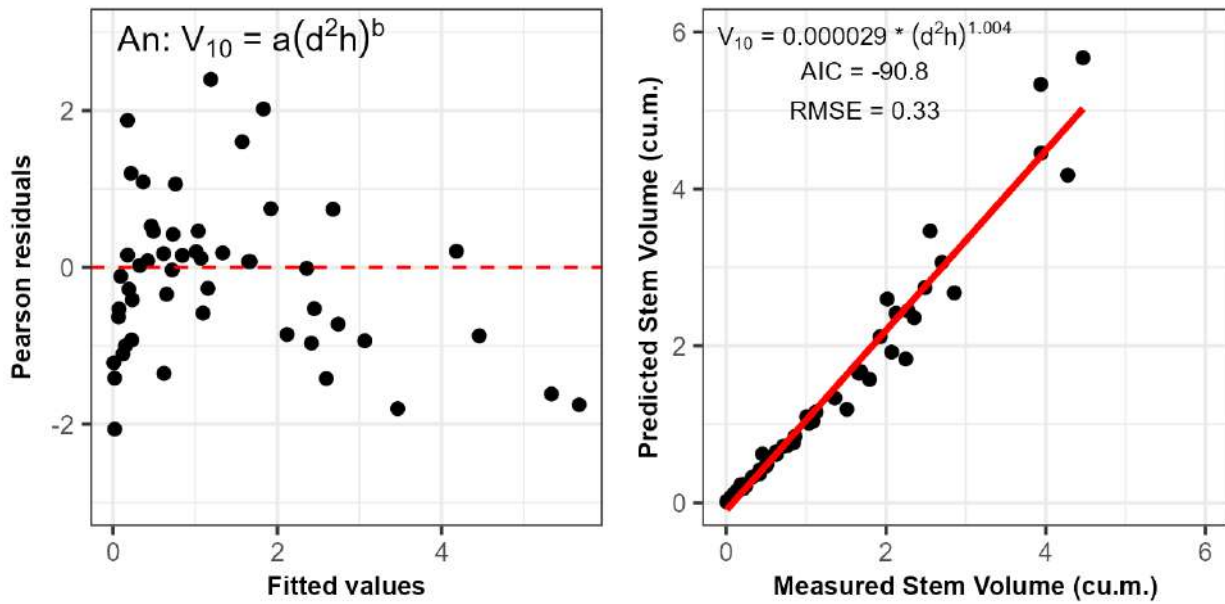
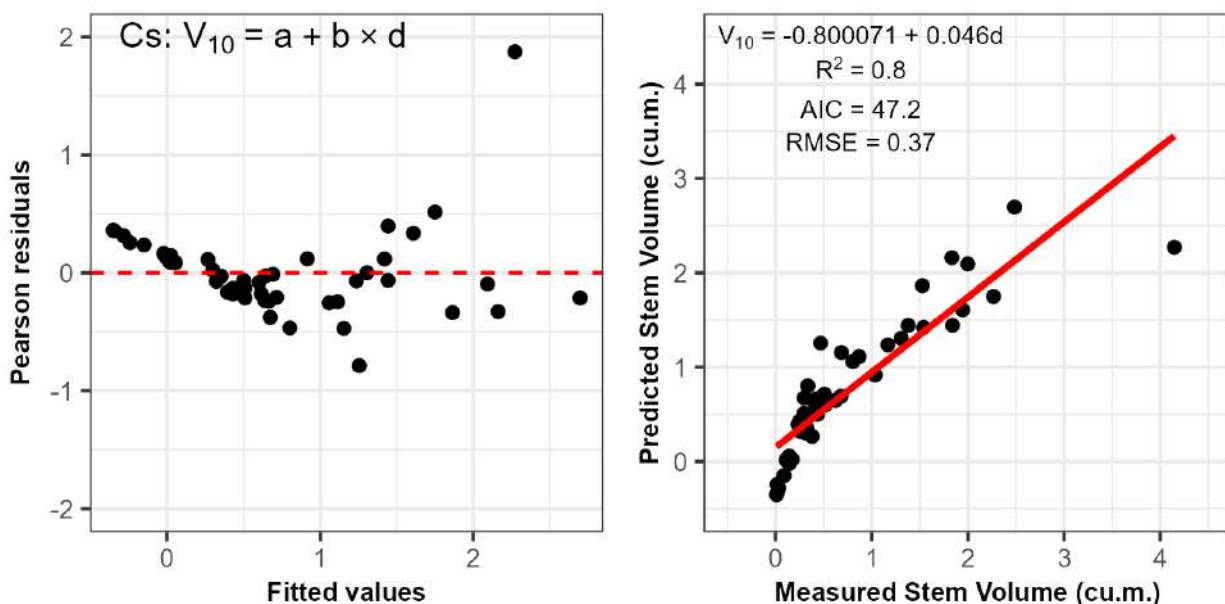
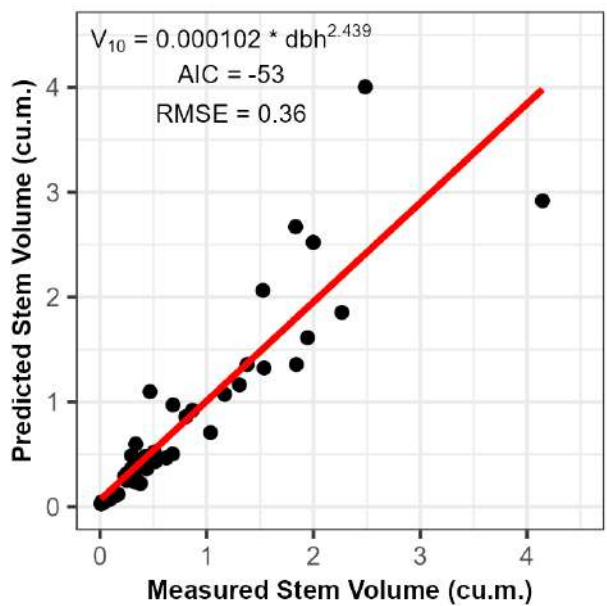
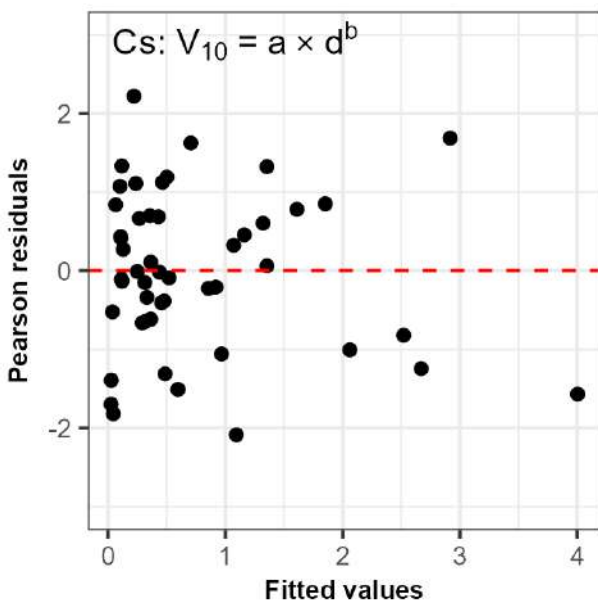
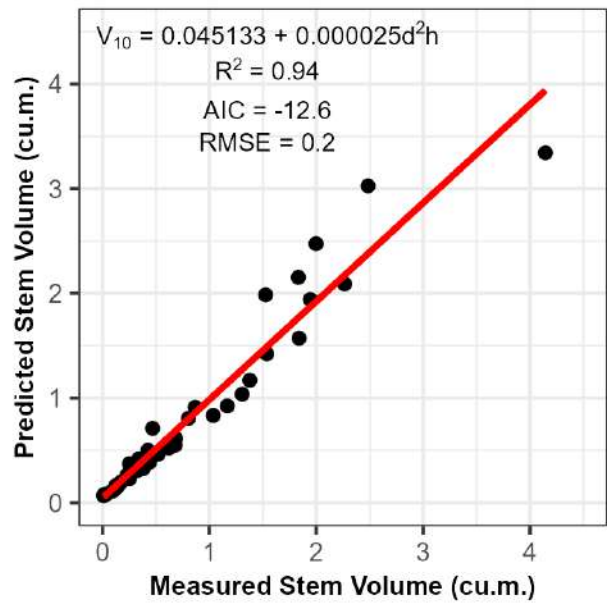
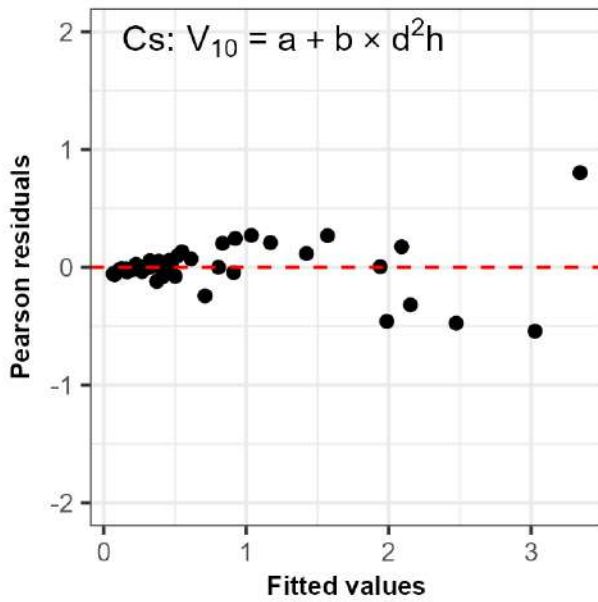
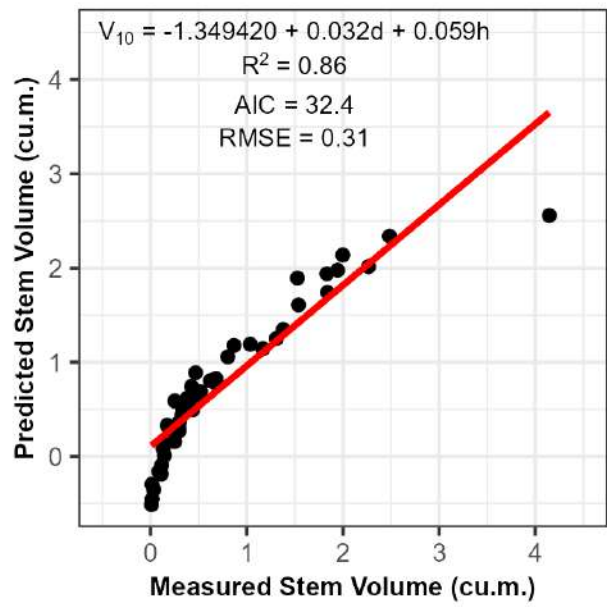
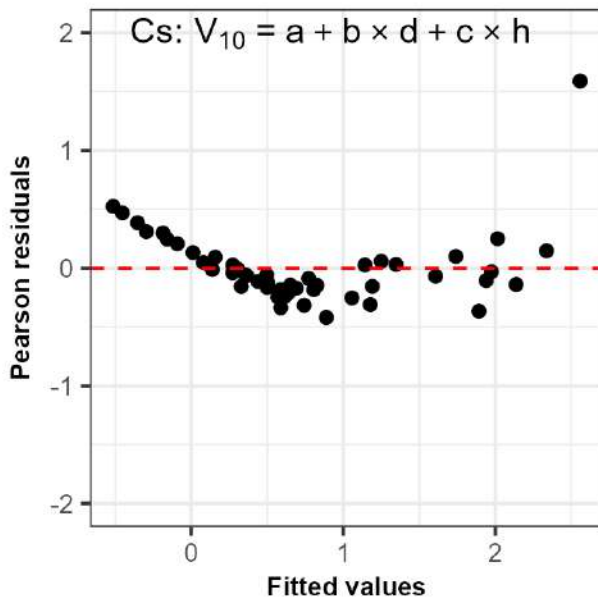


Figure 38: Left figures show the Pearsons residuals versus fitted values, indicating the distribution of errors, while right figures show the relationship between predicted versus the measured stem volume up to 10cm diameter of *Alnus nepalensis*. Models' performance is summarized by the equations, AIC, and RMSE for each model in the right figures. For tree code (An, Cs, Lp, Sw, Pr, Sr, Ta) refer Table 1.

Table A5.3: Summary of performance metrics for candidate models of *Castanopsis* spp. for volume (under bark) up to top 10cm. (All displayed parameters are significant at 5%).

Model	Equation	n	a	b	c	AIC	RMSE	R ²	MB
M1	$V = a + b * d$	49	-0.80007	0.045772	-	47.22	0.8	0.37	-
M2	$V = a + b * d + c * h$	49	-1.34942	0.032487	0.058761	32.43	0.86	0.32	-
M3	$V = a + b * d^2h$	49	0.045133	0.000025	-	-12.61	0.94	0.21	-
M4	$V = a * d^b$	49	0.000102	2.438689	-	-53	-	0.36	-0.03
M5	$V = a * d^b * h^c$	49	0.000025	1.848871	1.220024	-91.4	-	0.18	-0.02
M6	$V = a * (d^2h)^b$	49	0.000031	0.987658	-	-96.8	-	0.21	-0.03





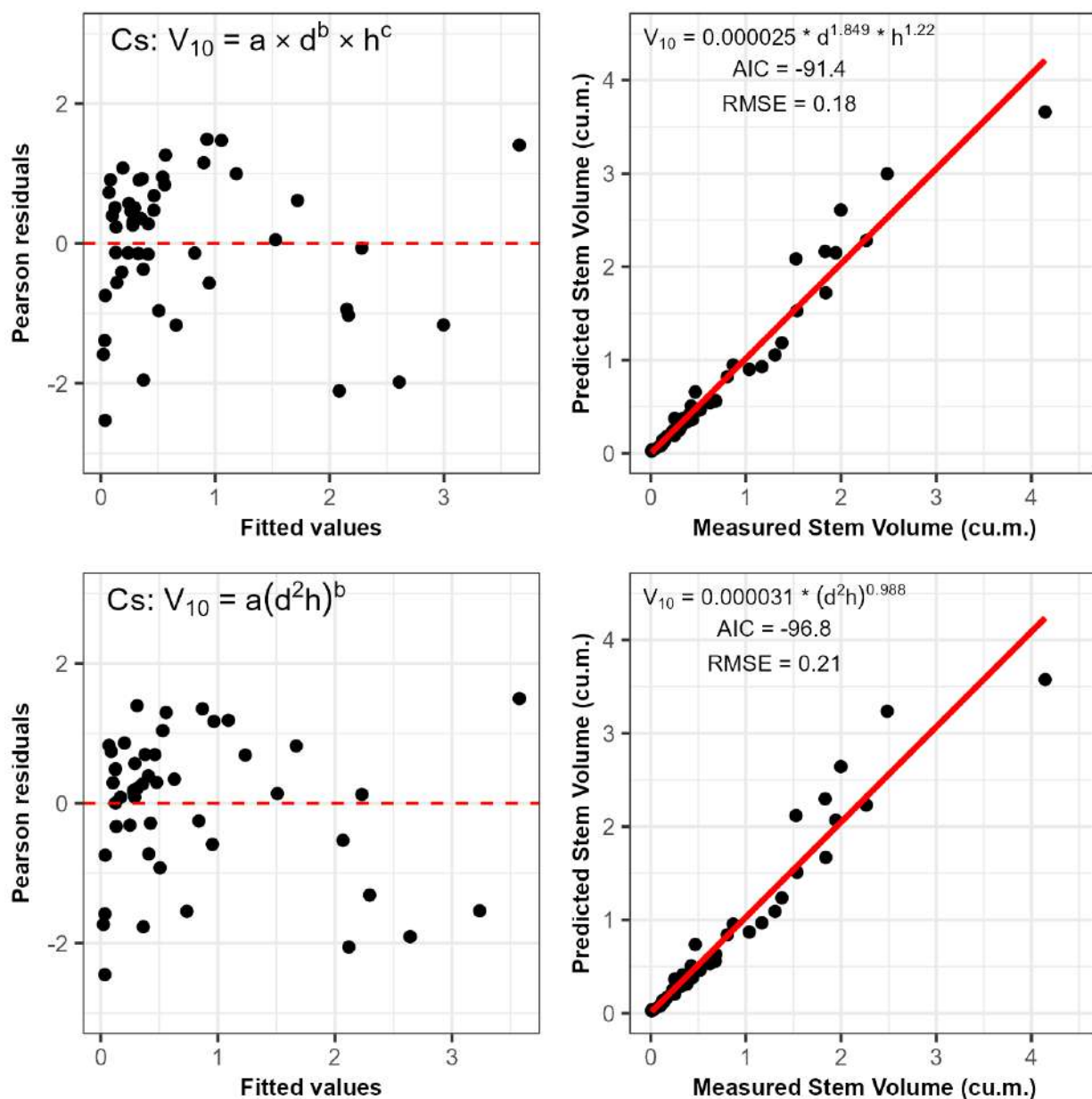
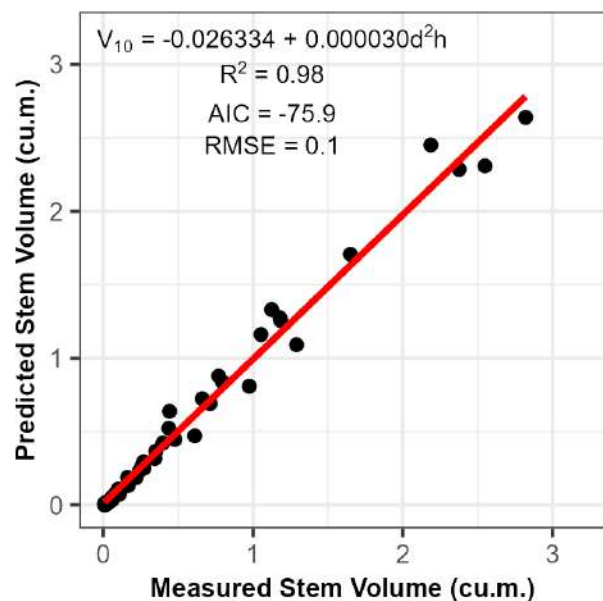
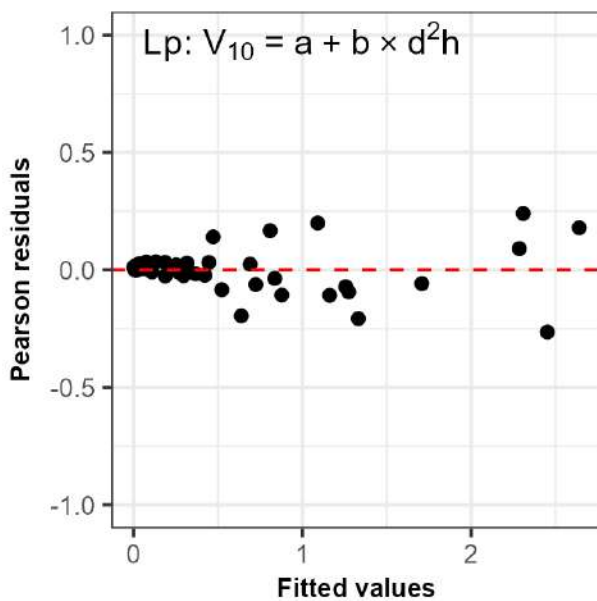
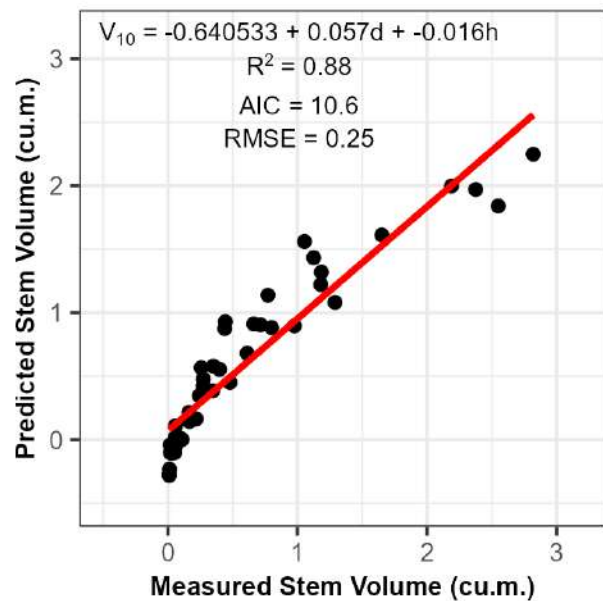
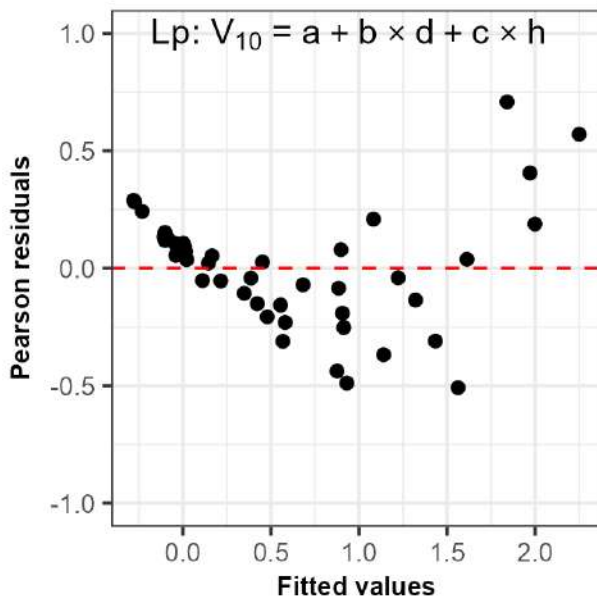
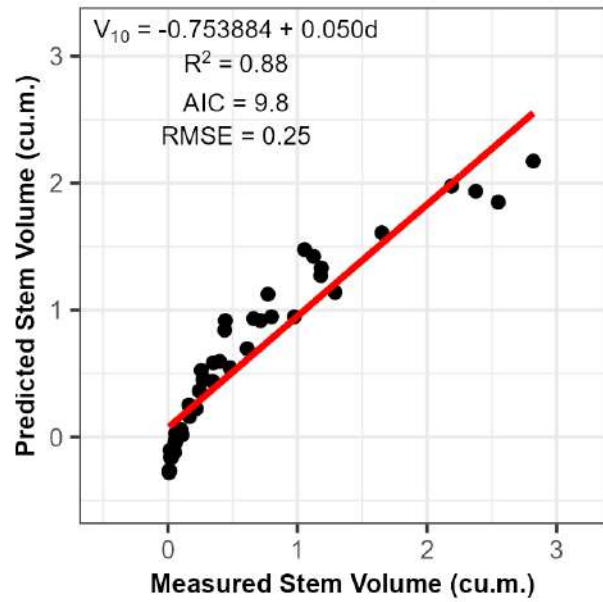
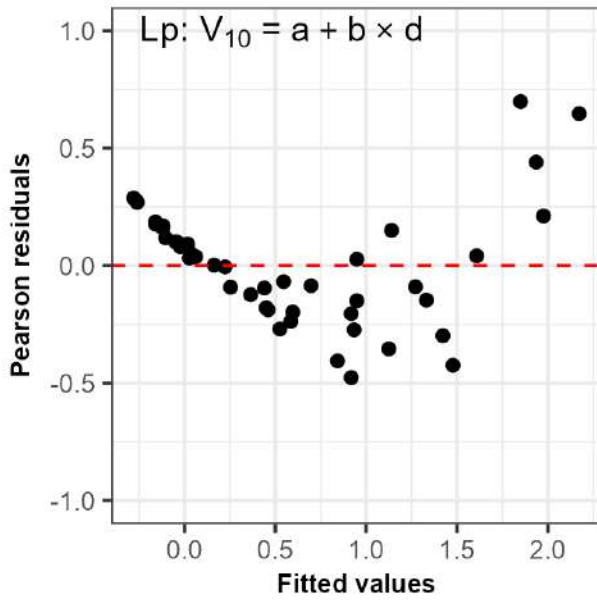


Figure A5.3: Left figures show the Pearsons residuals versus fitted values, indicating the distribution of errors, while right figures show the relationship between predicted versus the measured stem volume up to 10cm diameter of *Castanopsis* spp. Models' performance is summarized by the equations, AIC, and RMSE for each model in the right figures. For tree code (An, Cs, Lp, Sw, Pr, Sr, Ta) refer Table 1.

Table A5.4: Summary of performance metrics for candidate models of *Lagerstroemia parviflora* for volume (under bark) up to top 10cm. (All displayed parameters are significant at 5%).

Model	Equation	n	a	b	c	AIC	RMSE	R ²	MB
M1	$V = a + b * d$	44	-0.75388	0.050373	-	9.83	0.88	0.26	-
M2	$V = a + b * d + c * h$	44	-0.64053	0.056987	-0.01589	10.59	0.89	0.25	-
M3	$V = a + b * d^2h$	44	-0.02633	0.00003	-	-75.87	0.99	0.1	-
M4	$V = a * d^b$	44	0.000037	2.793937	-	-98.9	-	0.15	-0.02
M5	$V = a * d^b * h^c$	44	0.000009	1.908653	1.469238	-127	-	0.09	-1.00E-02
M6	$V = a * (d^2h)^b$	44	0.000014	1.068129	-	-131.2	-	0.09	-0.01



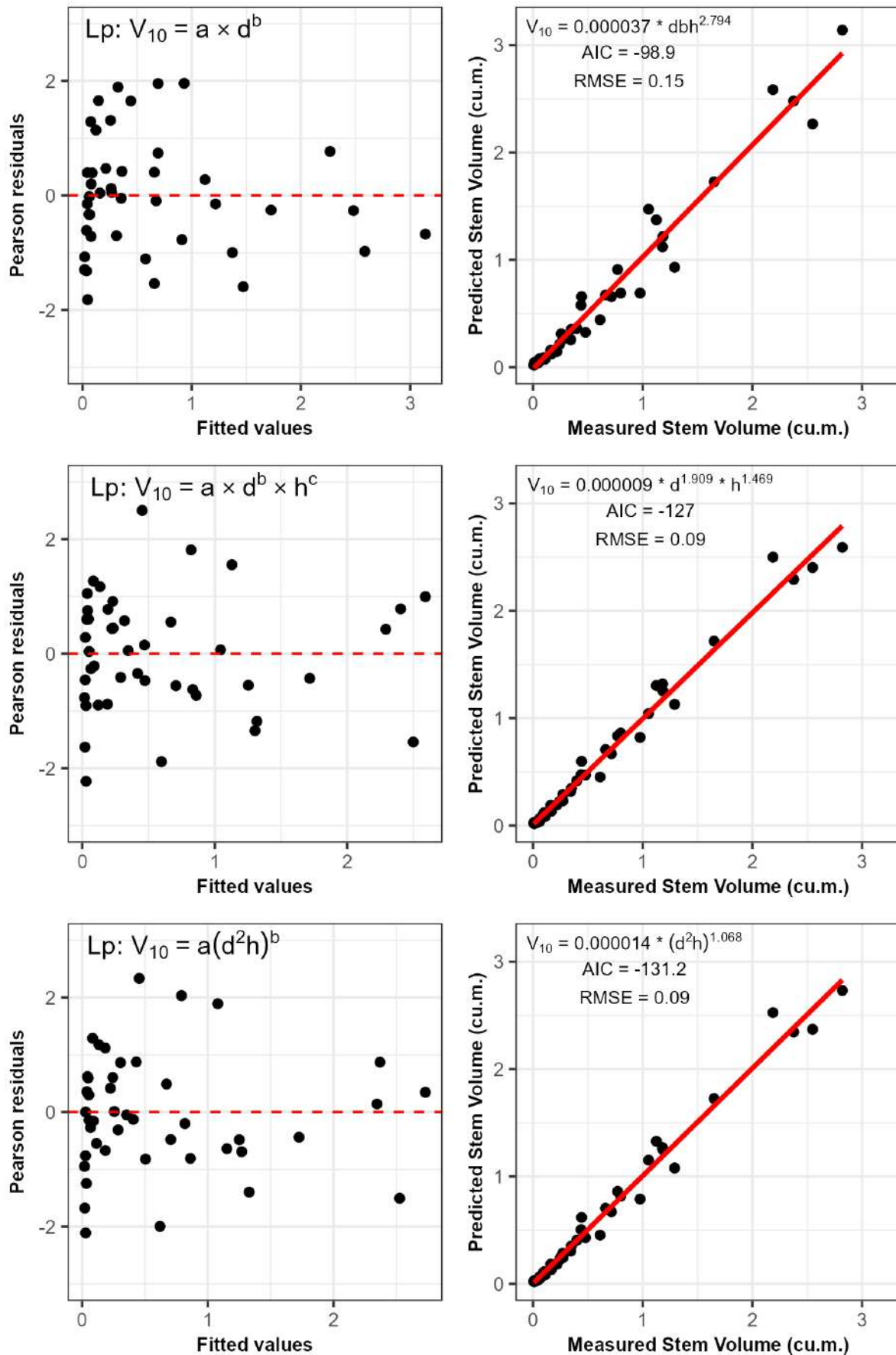
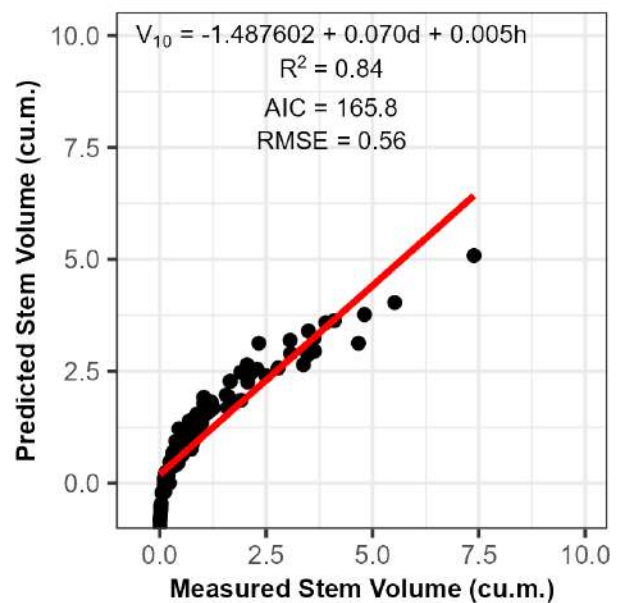
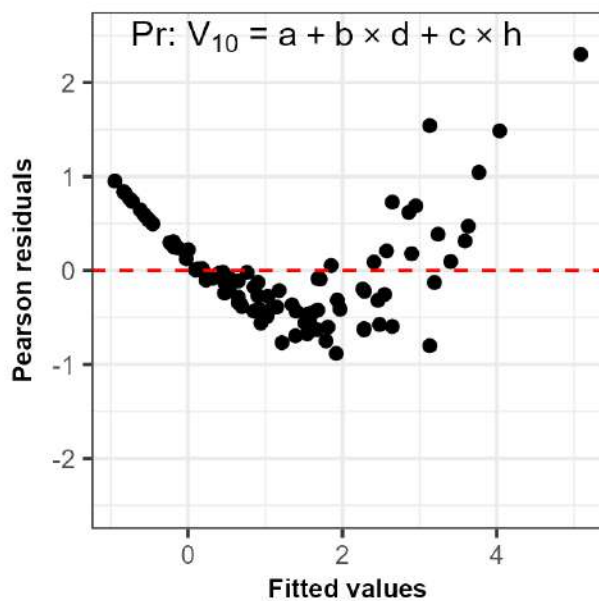
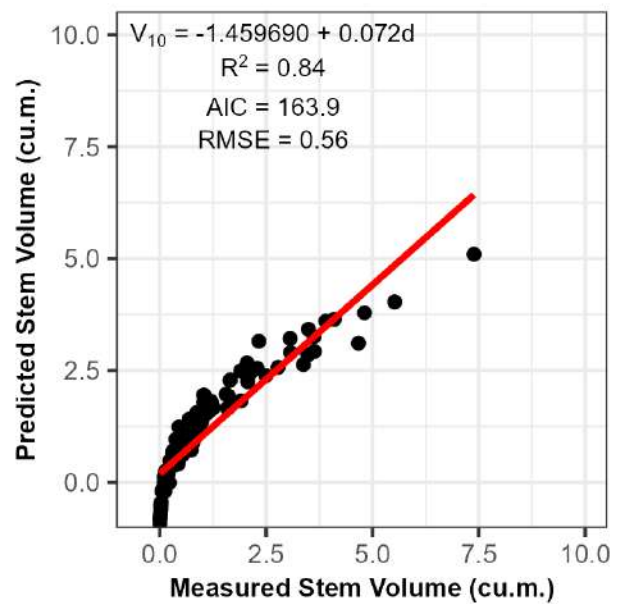
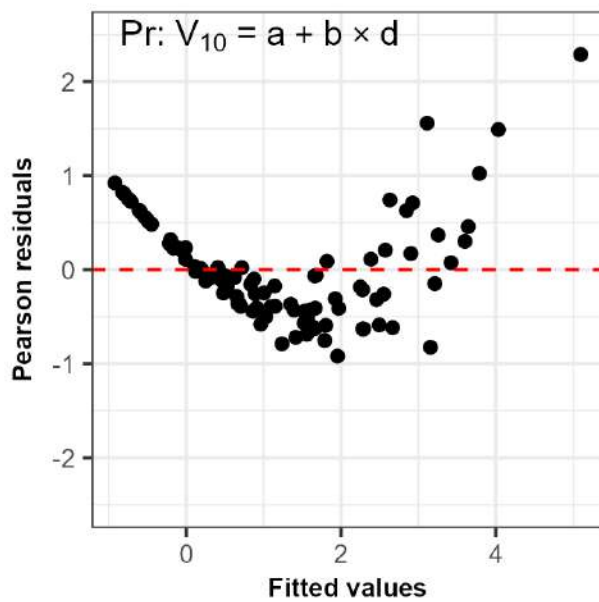
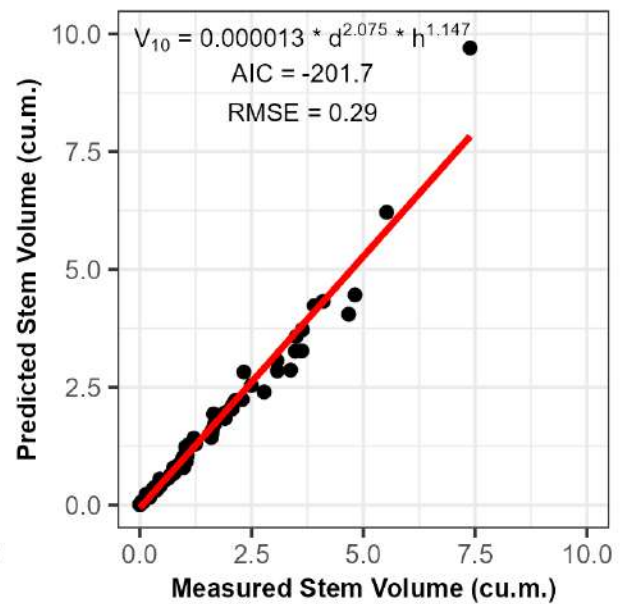
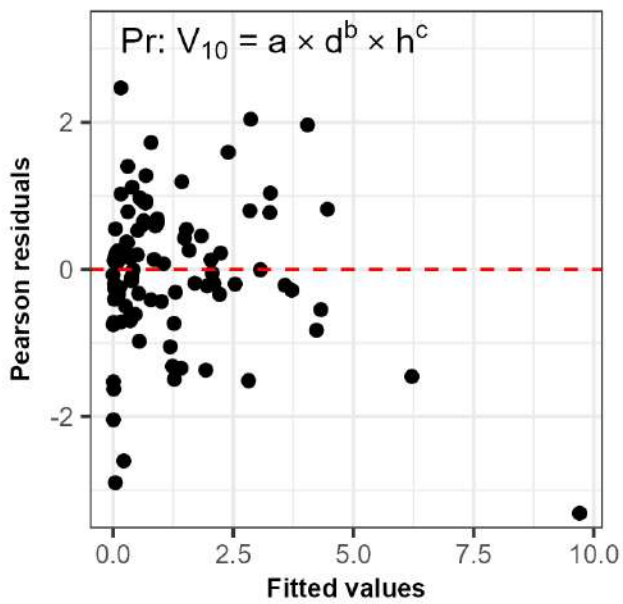
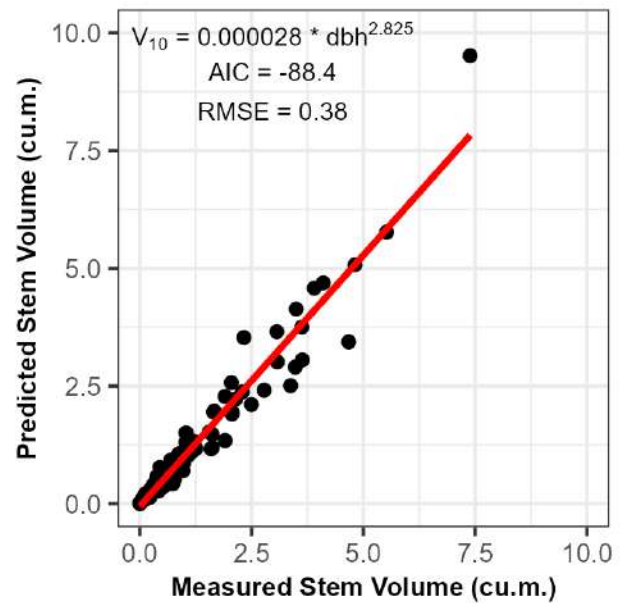
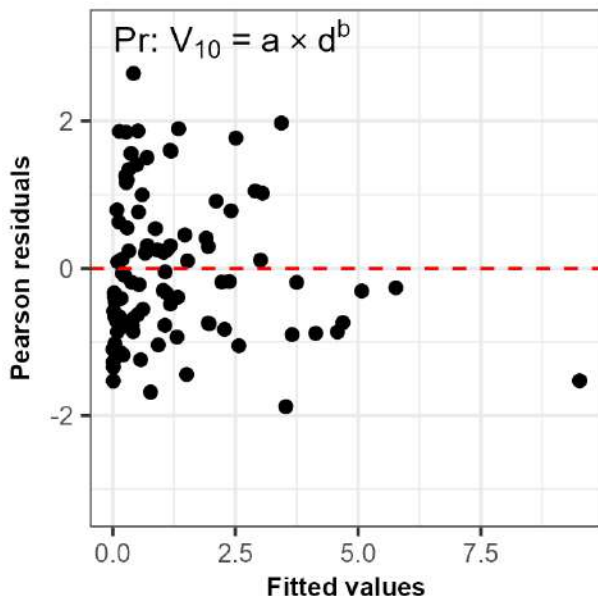
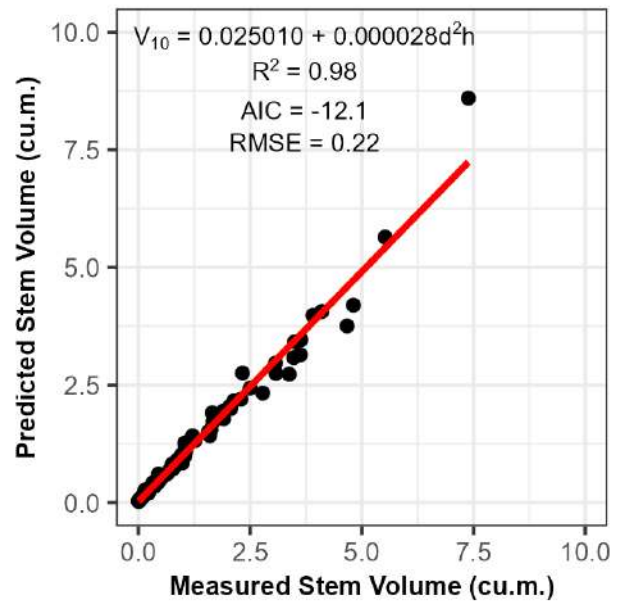
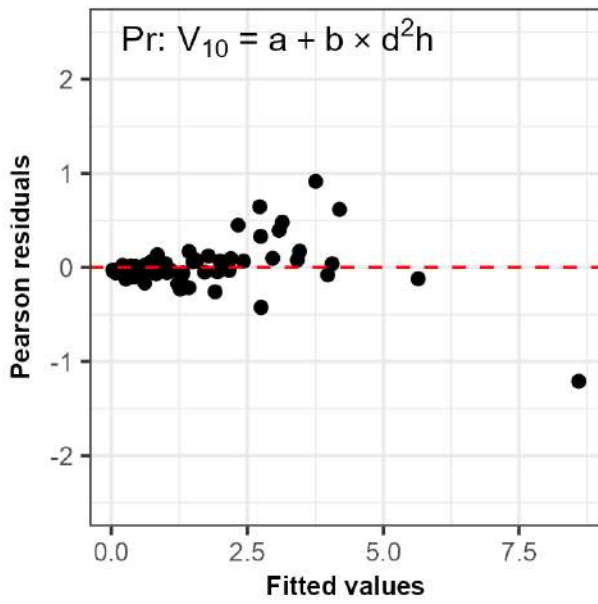


Figure A5.4: Left figures show the Pearsons residuals versus fitted values, indicating the distribution of errors, while right figures show the relationship between predicted versus the measured stem volume up to 10cm diameter of *Lagerstroemia parviflora*. Models' performance is summarized by the equations, AIC, and RMSE for each model in the right figures. For tree code (An, Cs, Lp, Sw, Pr, Sr, Ta) refer Table 1.

Table A5.5: Summary of performance metrics for candidate models of *Pinus roxburghii* for volume (under bark) up to top 10cm. (All displayed parameters are significant at 5%).

Model	Equation	n	a	b	c	AIC	RMSE	R ²	MB
M1	$V = a + b * d$	94	-1.45969	0.071874	-	163.92	0.85	0.57	-
M2	$V = a + b * d + c * h$	94	-1.4876	0.070242	0.004603	165.82	0.85	0.57	-
M3	$V = a + b * d^2h$	94	0.02501	0.000028	-	-12.12	0.98	0.22	-
M4	$V = a * d^b$	94	0.000028	2.824988	-	-88.4	-	0.38	-0.03
M5	$V = a * d^b * h^c$	94	0.000013	2.075056	1.14691	-201.7	-	0.29	-0.02
M6	$V = a * (d^2h)^b$	94	0.000014	1.064049	-	-208.5	-	0.29	-0.03





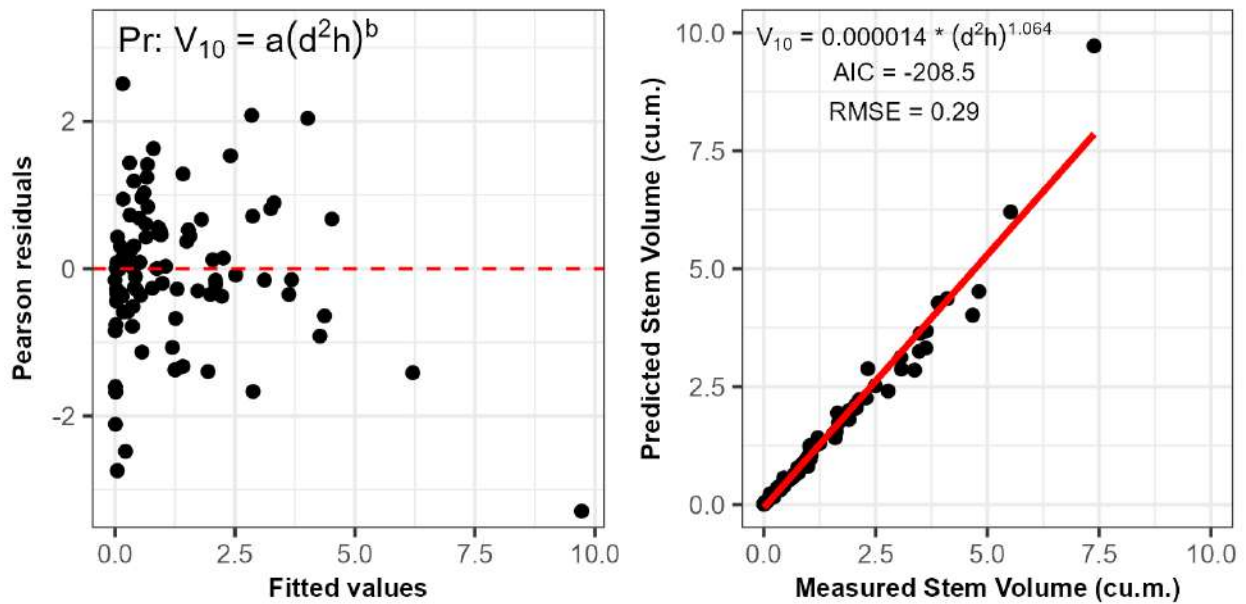
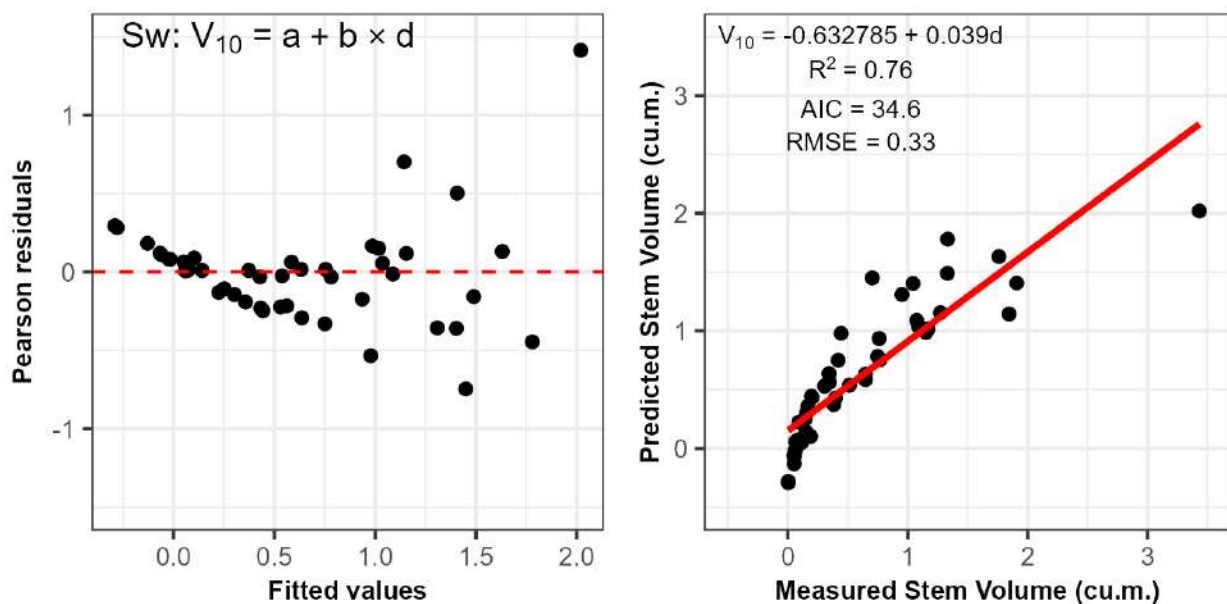
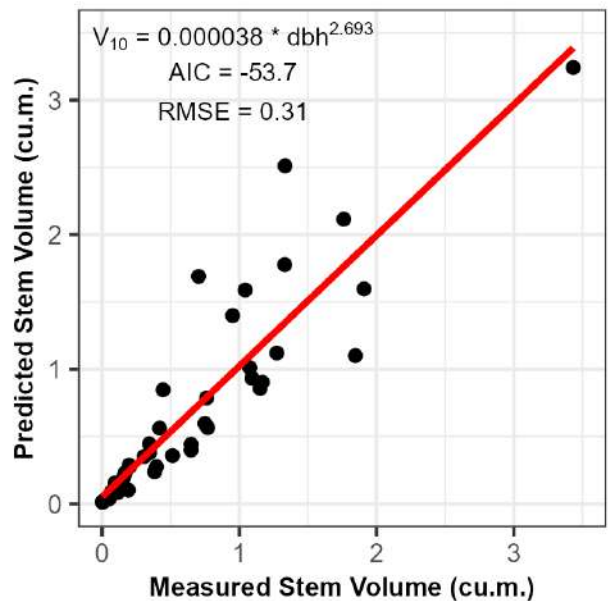
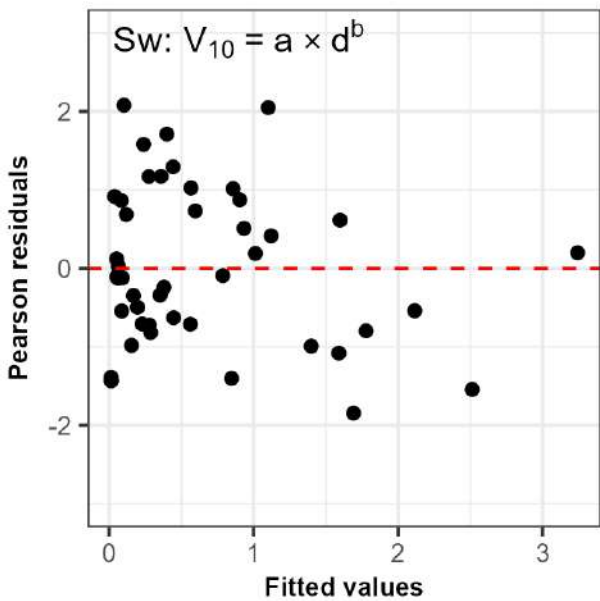
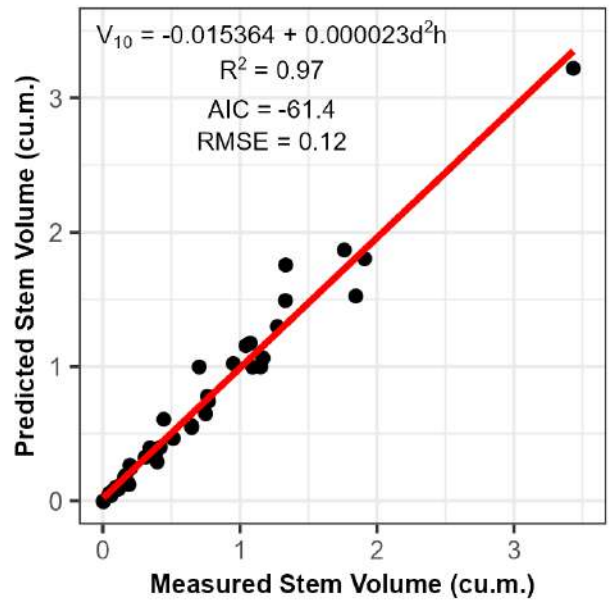
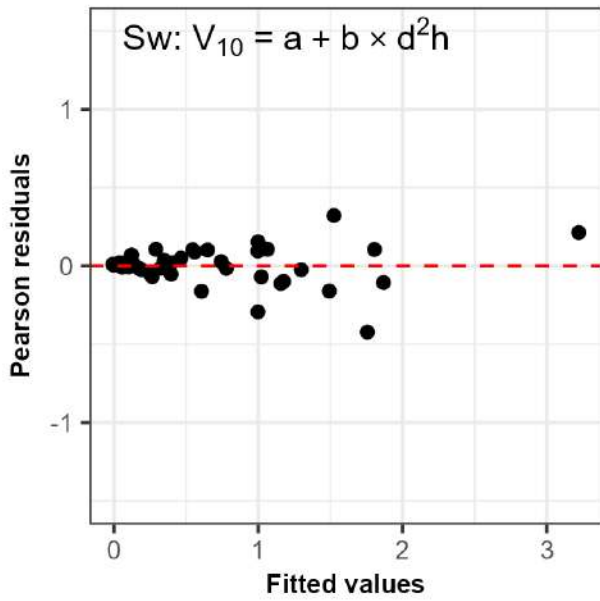
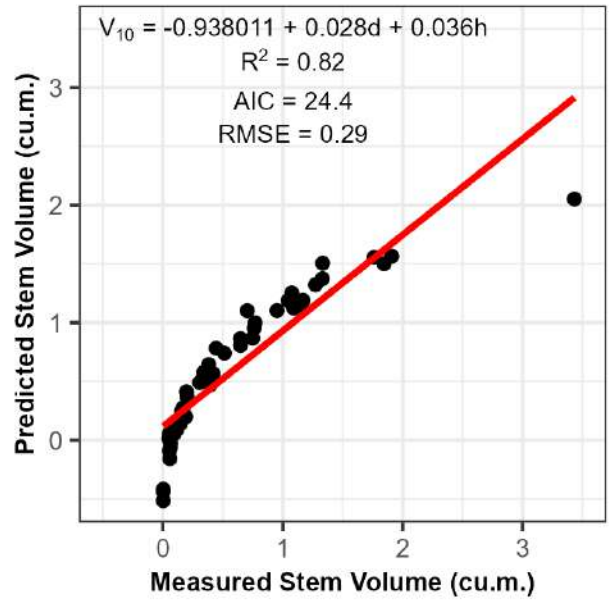
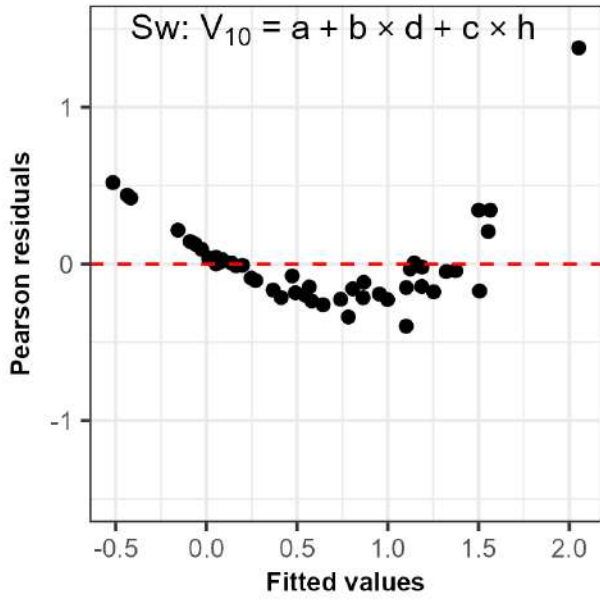


Figure A5.5: Left figures show the Pearsons residuals versus fitted values, indicating the distribution of errors, while right figures show the relationship between predicted versus the measured stem volume up to 10cm diameter of *Pinus roxburghii*. Models' performance is summarized by the equations, AIC, and RMSE for each model in the right figures. For tree code (An, Cs, Lp, Sw, Pr, Sr, Ta) refer Table 1.

Table A5.6: Summary of performance metrics for candidate models of *Schima wallichii* for volume (under bark) up to top 10cm. (All displayed parameters are significant at 5%).

Model	Equation	n	a	b	c	AIC	RMSE	R ²	MB
M1	$V = a + b * d$	46	-0.63279	0.039288	-	34.61	0.76	0.34	-
M2	$V = a + b * d + c * h$	46	-0.93801	0.027792	0.036091	24.38	0.82	0.29	-
M3	$V = a + b * d^2h$	46	-0.01536	0.000023	-	-61.39	0.98	0.12	-
M4	$V = a * d^b$	46	0.000038	2.693065	-	-53.7	-	0.31	-0.04
M5	$V = a * d^b * h^c$	46	0.00001	1.765752	1.523197	-139	-	0.06	-1.00E-02
M6	$V = a * (d^2h)^b$	46	0.000015	1.04114	-	-120.8	-	0.12	-0.03





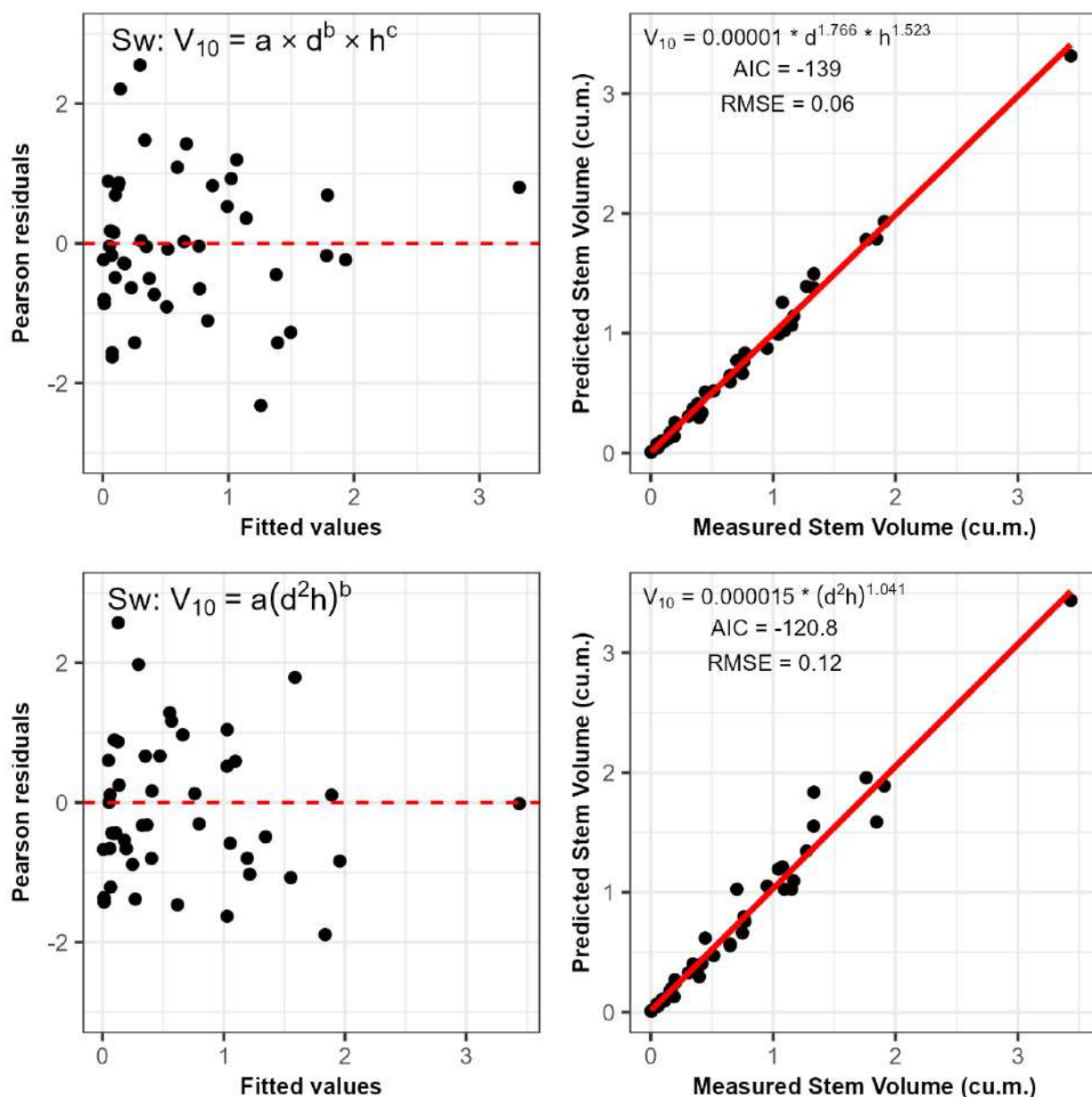
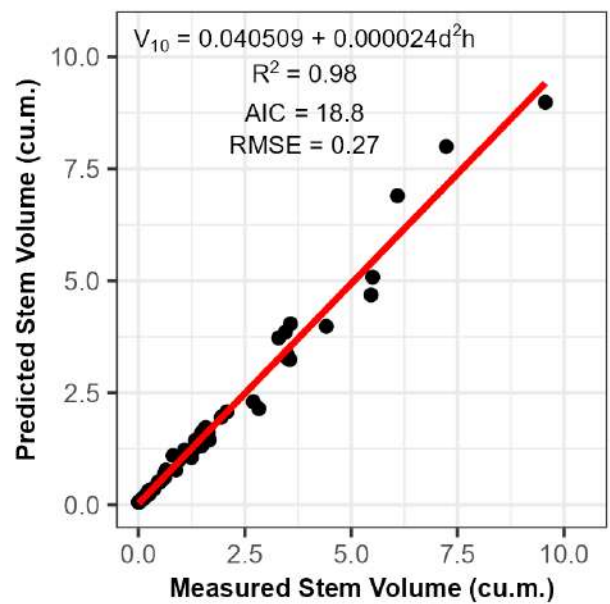
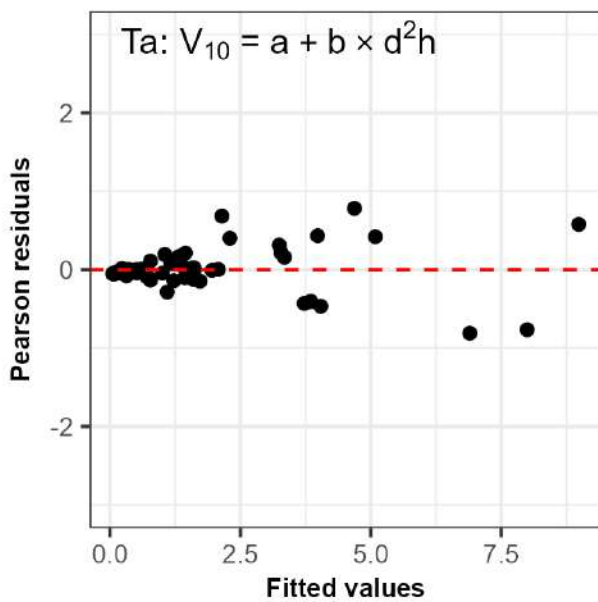
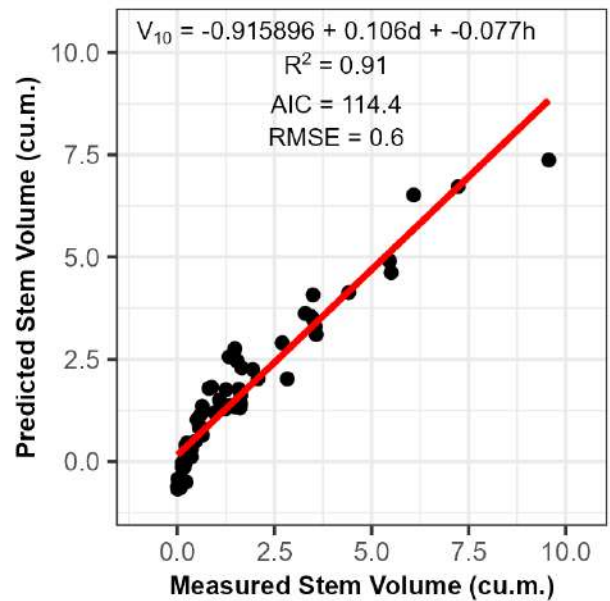
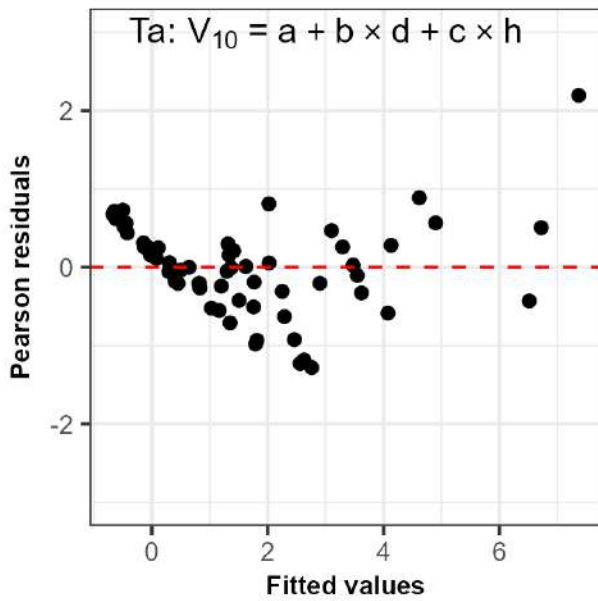
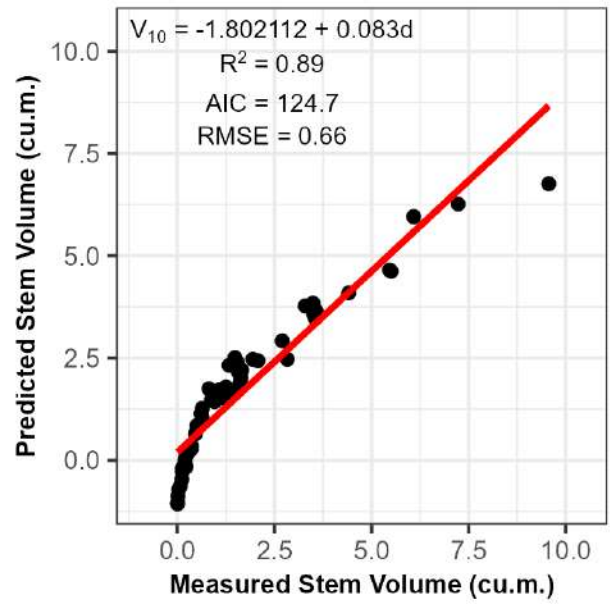
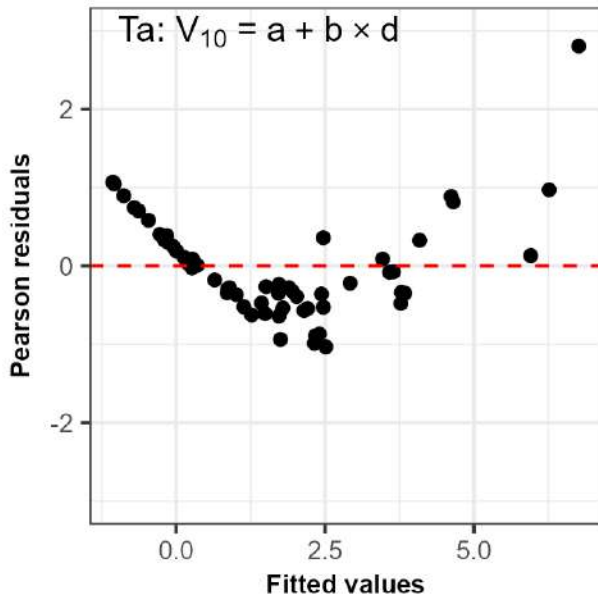


Figure A5.6: Left figures show the Pearsons residuals versus fitted values, indicating the distribution of errors, while right figures show the relationship between predicted versus the measured stem volume up to 20cm diameter of *Schima wallichii*. Models' performance is summarized by the equations, AIC, and RMSE for each model in the right figures. For tree code (An, Cs, Lp, Sw, Pr, Sr, Ta) refer Table 1.

Table A5.7: Summary of performance metrics for candidate models of *Terminalia alata* for volume (under bark) up to top 10cm.

Model	Equation	n	a	b	c	AIC	RMSE	R ²	MB
M1	$V = a + b * d$	59	-1.80211	0.082958	-	124.74	0.89	0.67	-
M2	$V = a + b * d + c * h$	59	-0.9159	0.106334	-0.07722	114.42	0.91	0.6	-
M3	$V = a + b * d^2h$	59	0.040509	0.000024	-	18.82	0.99	0.27	-
M4	$V = a * d^b$	59	0.000084	2.535475	-	-41.6	-	0.47	-0.05
M5	$V = a * d^b * h^c$	59	0.000018	1.953711	1.15901	-81.6	-	0.28	-0.02
M6	$V = a * (d^2h)^b$	59	0.000021	1.013348	-	-88.6	-	0.29	-0.02



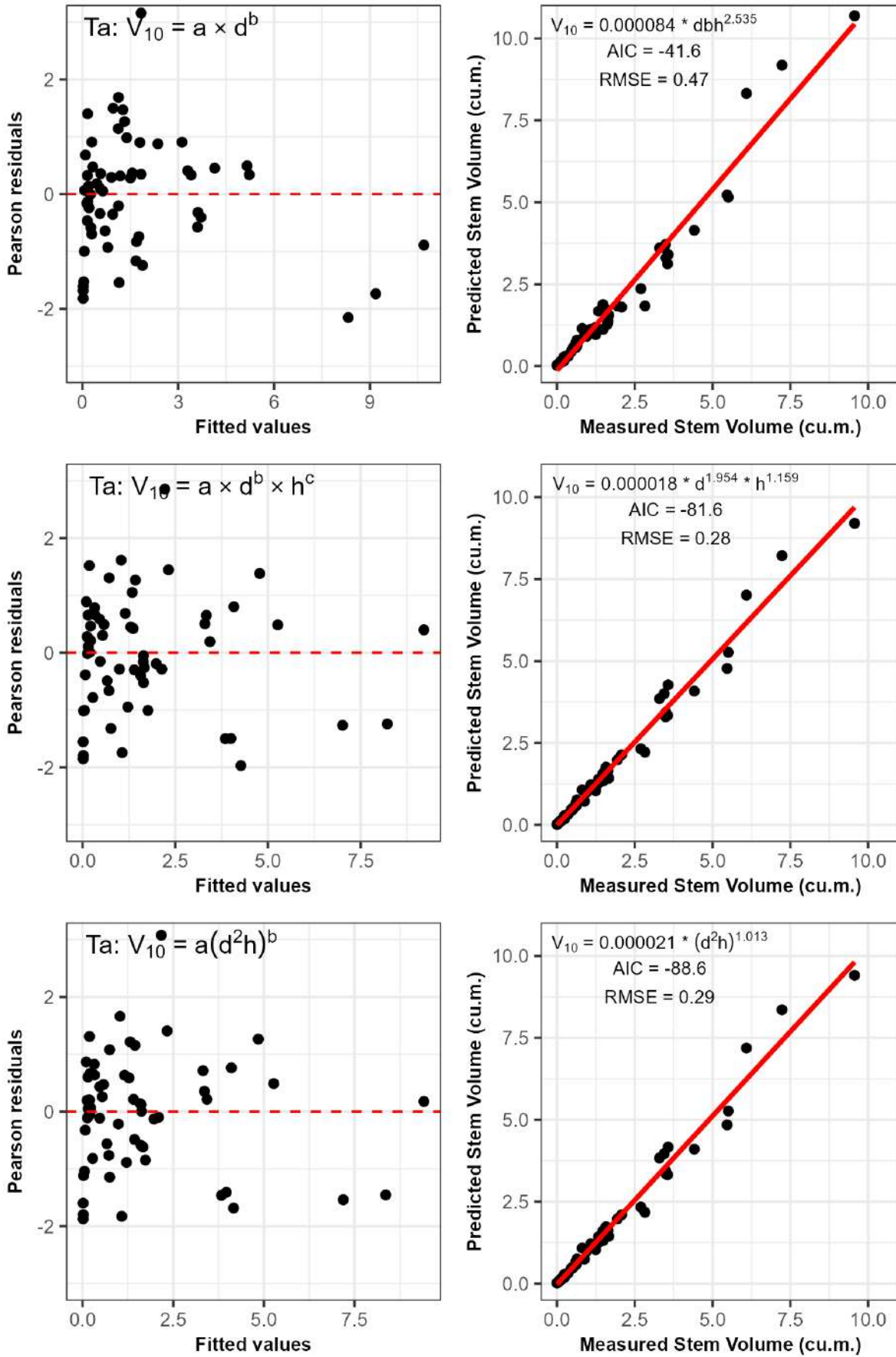


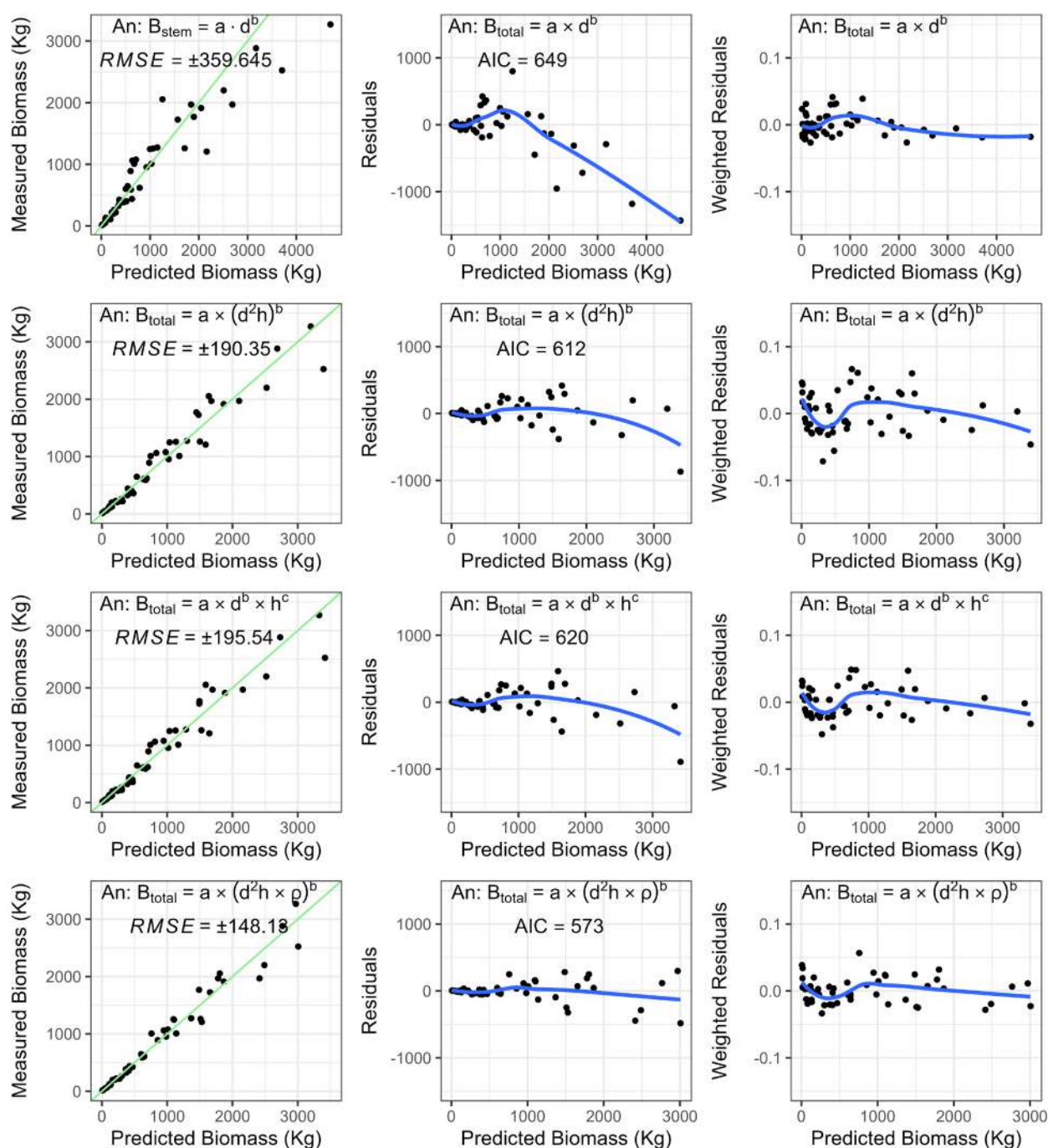
Figure A5.7: Left figures show the Pearsons residuals versus fitted values, indicating the distribution of errors, while right figures show the relationship between predicted versus the measured stem volume up to 20cm diameter of *Terminalia alata*. Models' performance is summarized by the equations, AIC, and RMSE for each model in the right figures. For tree code (An, Cs, Lp, Sw, Pr, Sr, Ta) refer Table 1.

Annex VI

Summary of Total Biomass Models Tested

Table A6.1: Summary of performance metrics for candidate models of *Alnus nepalensis* for total biomass. (All displayed parameters are significant at 5%).

Equation	n	w	a	b	c	AIC	RMSE	MB
$B = a \cdot d^b$	52	2.5512	0.079347	2.484165	-	649.27	359.65	-58.01
$B = a \cdot d^{2h^b}$	52	2.273	0.024719	0.975157	-	612.18	190.35	-2.75
$B = a \cdot d^b \cdot h^c$	52	2.3625	0.029871	1.999361	0.861472	619.63	195.54	-8.53
$B = a \cdot d^{2h} \rho^b$	52	2.3025	0.067139	0.956808	-	572.91	148.13	-6.34
$B = a \cdot d^{2h^b} \cdot (\rho)^c$	52	2.2966	0.101024	0.948358	1.346414	575.53	145.49	-1.97



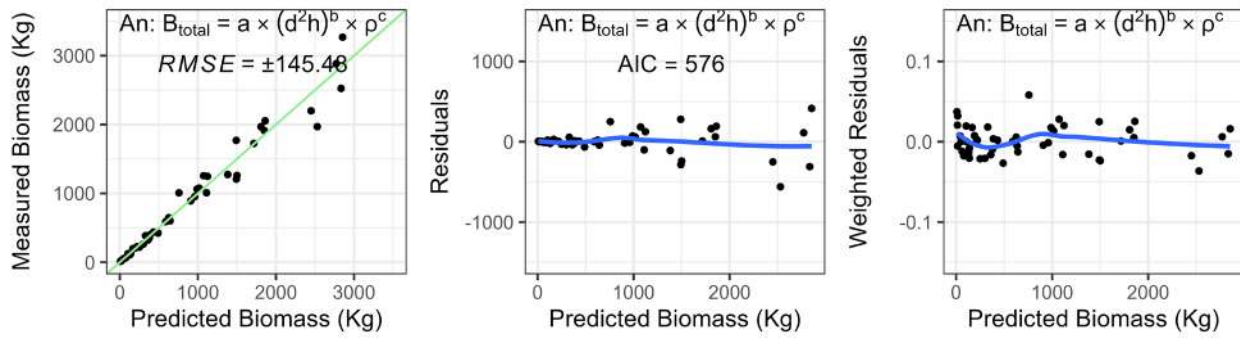
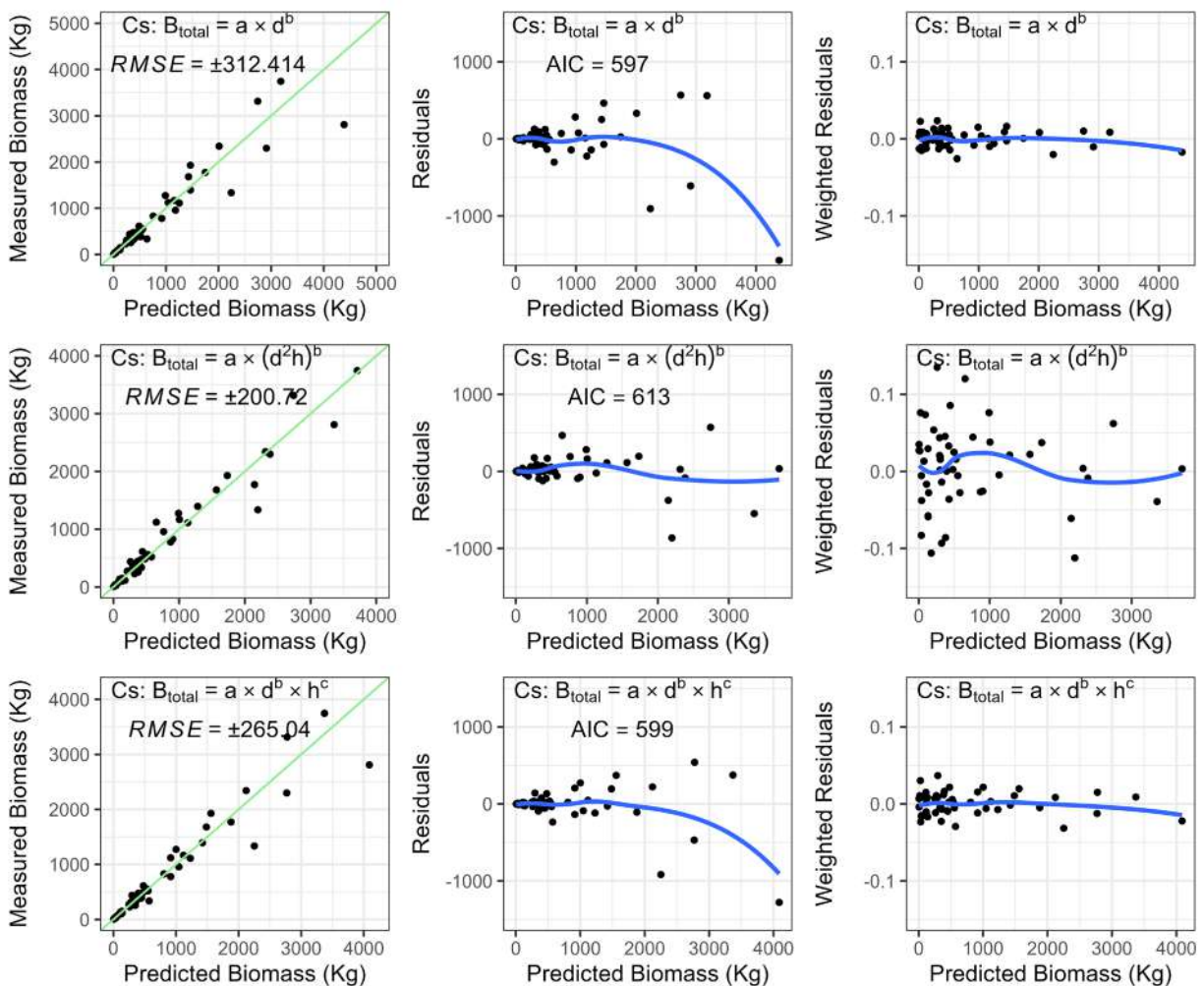


Figure A6.1: Shows the five model's performance for the total tree biomass of *Alnus nepalensis*, (a) shows the comparison between predicted and actual biomass, (b) displays the residuals against the predicted biomass, (c) shows the weighted residuals against the predicted biomass For tree code (An, Cs, Lp, Sw, Pr, Sr, Ta) refer Table 1.

Table A6.2: Summary of performance metrics for candidate models of *Castanopsis* spp. for total biomass. (All displayed parameters are significant at 5%).

Equation	n	w	a	b	c	AIC	RMSE	MB
$B = a * d^b$	52	2.6351	0.098381	2.46889	-	597.28	312.42	-22.04
$B = a * d^{2h^b}$	52	2.2016	0.032572	0.987245	-	612.66	200.72	8.15
$B = a * d^b * ht^c$	52	2.5289	0.071253	2.318525	0.299393	599.49	265.05	-18.14
$B = a * d^{2h^b}$	52	2.2511	0.079997	0.965858	-	611.55	205.18	9.98
$B = a * d^{2h^b} * (\rho)^c$	52	2.2301	0.053685	0.975874	0.539927	617.62	200.5	7.02



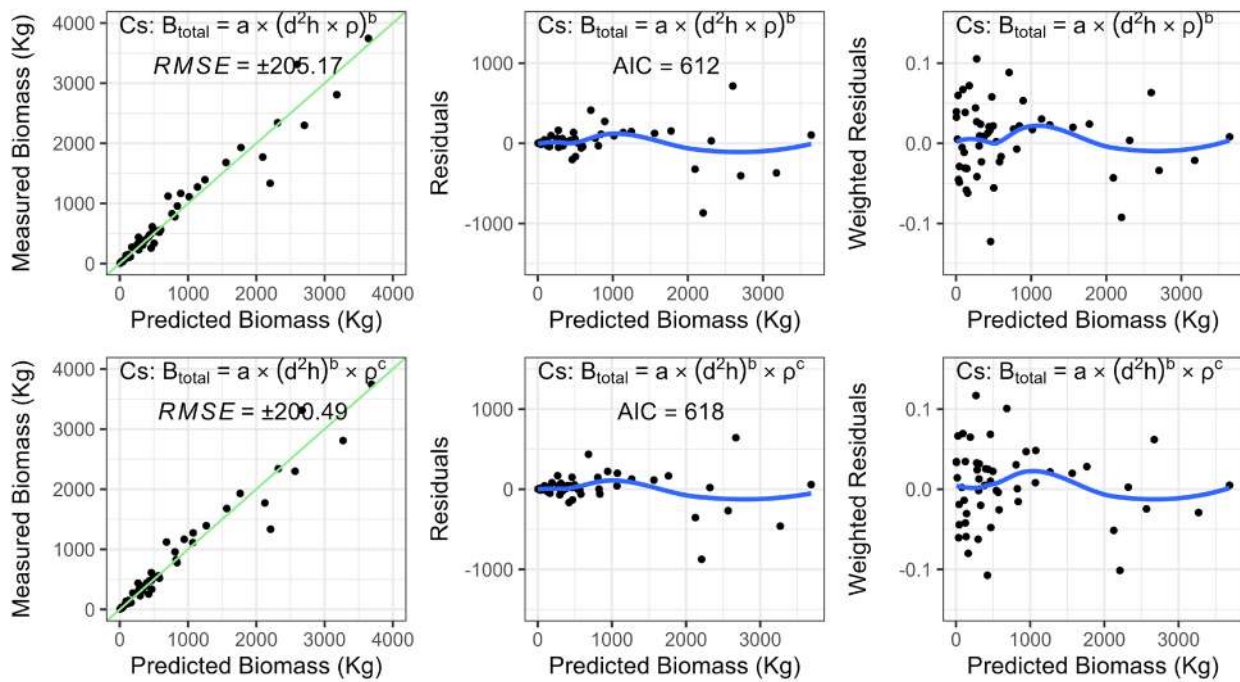
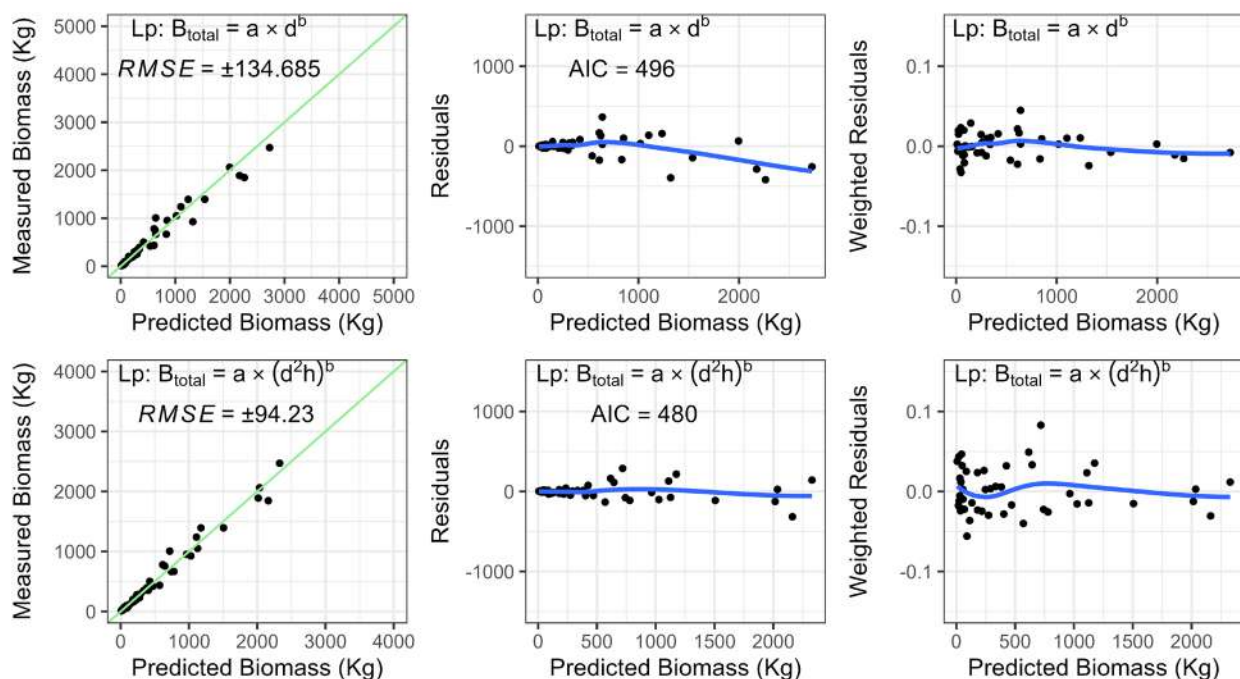


Figure A6.2: Shows the five model's performance for the total tree biomass of *Castanopsis* spp, (a) shows the comparison between predicted and actual biomass, (b) displays the residuals against the predicted biomass, (c) shows the weighted residuals against the predicted biomass. For tree code (An, Cs, Lp, Sw, Pr, Sr, Ta) refer Table 1.

Table A6.3: Summary of performance metrics for candidate models of *Lagerstroemia parviflora* for total biomass. (All displayed parameters are significant at 5%).

Equation	n	w	a	b	c	AIC	RMSE	MB
$B = a * d^b$	46	2.5579	0.052504	2.672869	-	496.05	134.69	-13.78
$B = a * d^{2h^b}$	46	2.3157	0.022636	1.01224	-	480.46	94.23	-1.01
$B = a * d^b * ht^c$	46	2.4002	0.027651	2.158233	0.796044	487.27	97.67	-4.73
$B = a * d^{2h}p^b$	46	2.279	0.060964	0.971369	-	455.64	80.37	-2.1
$B = a * d^{2h} * (\rho)^c$	46	2.2683	0.066084	0.968054	1.052883	463.43	79.96	-1.64



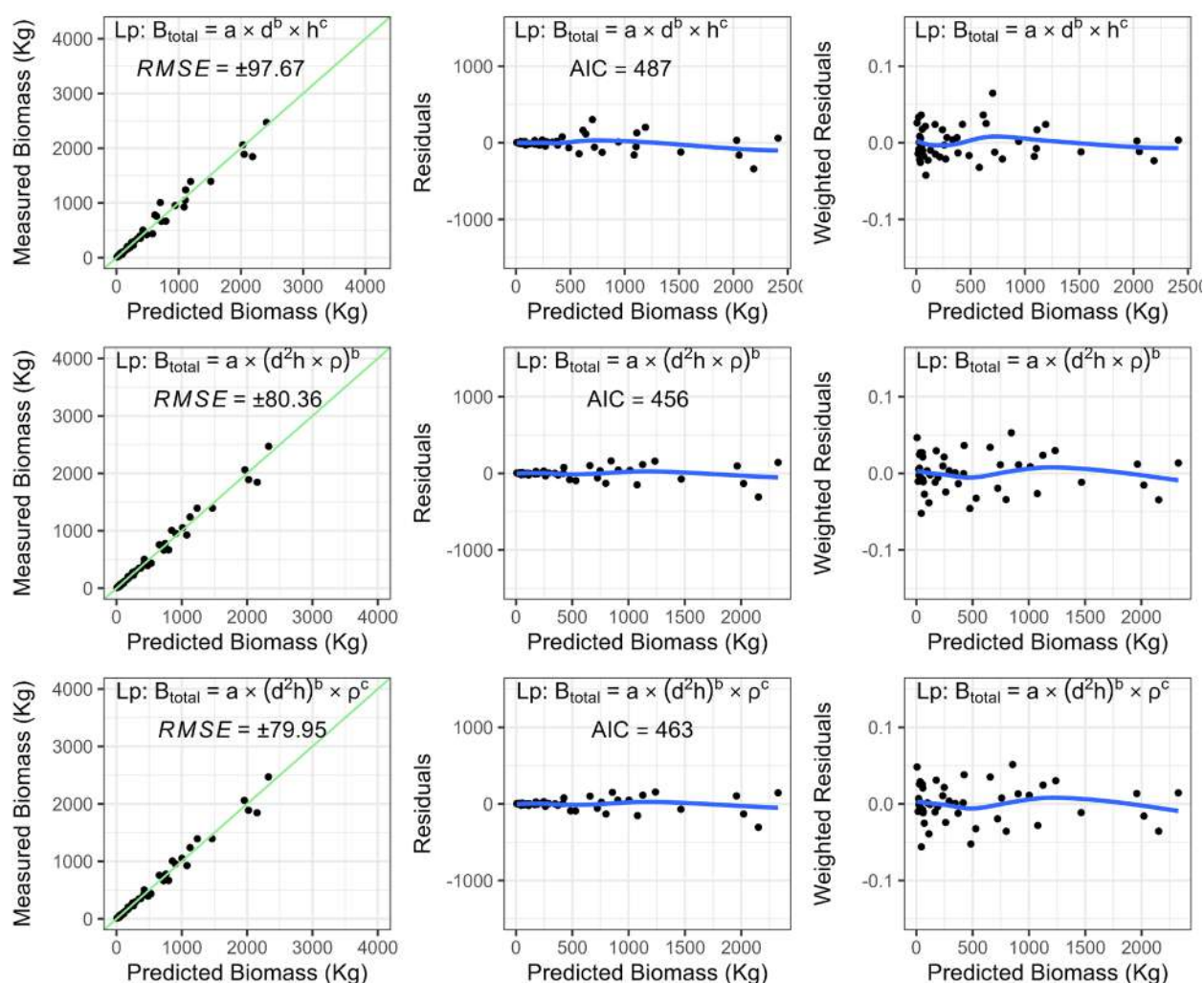


Figure A6.3: Shows the five model's performance for the total tree biomass of *Lagerstroemia parviflora*, (a) shows the comparison between predicted and actual biomass, (b) displays the residuals against the predicted biomass, (c) shows the weighted residuals against the predicted biomass. For tree code (An, Cs, Lp, Sw, Pr, Sr, Ta) refer Table 1.

Table A6.4: Summary of performance metrics for candidate models of *Pinus roxburghii* for total biomass. (All displayed parameters are significant at 5%).

Equation	n	w	a	b	c	AIC	RMSE	MB
$B = a * d^b$	96	2.394	0.03786	2.707095	-	1139.34	252.59	-9.61
$B = a * d^2h^b$	96	2.434	0.024544	0.998721	-	1133.83	236.5	33.24
$B = a * d^b * ht^c$	96	2.5002	0.031693	2.329281	0.519366	1110.17	223.33	2.84
$B = a * d^2h^b$	96	2.5543	0.086571	0.944465	-	1110.78	226.58	30.49
$B = a * d^2h^b * (\rho)^c$	96	2.5567	0.082022	0.946485	0.899249	1118.71	226.29	30.85

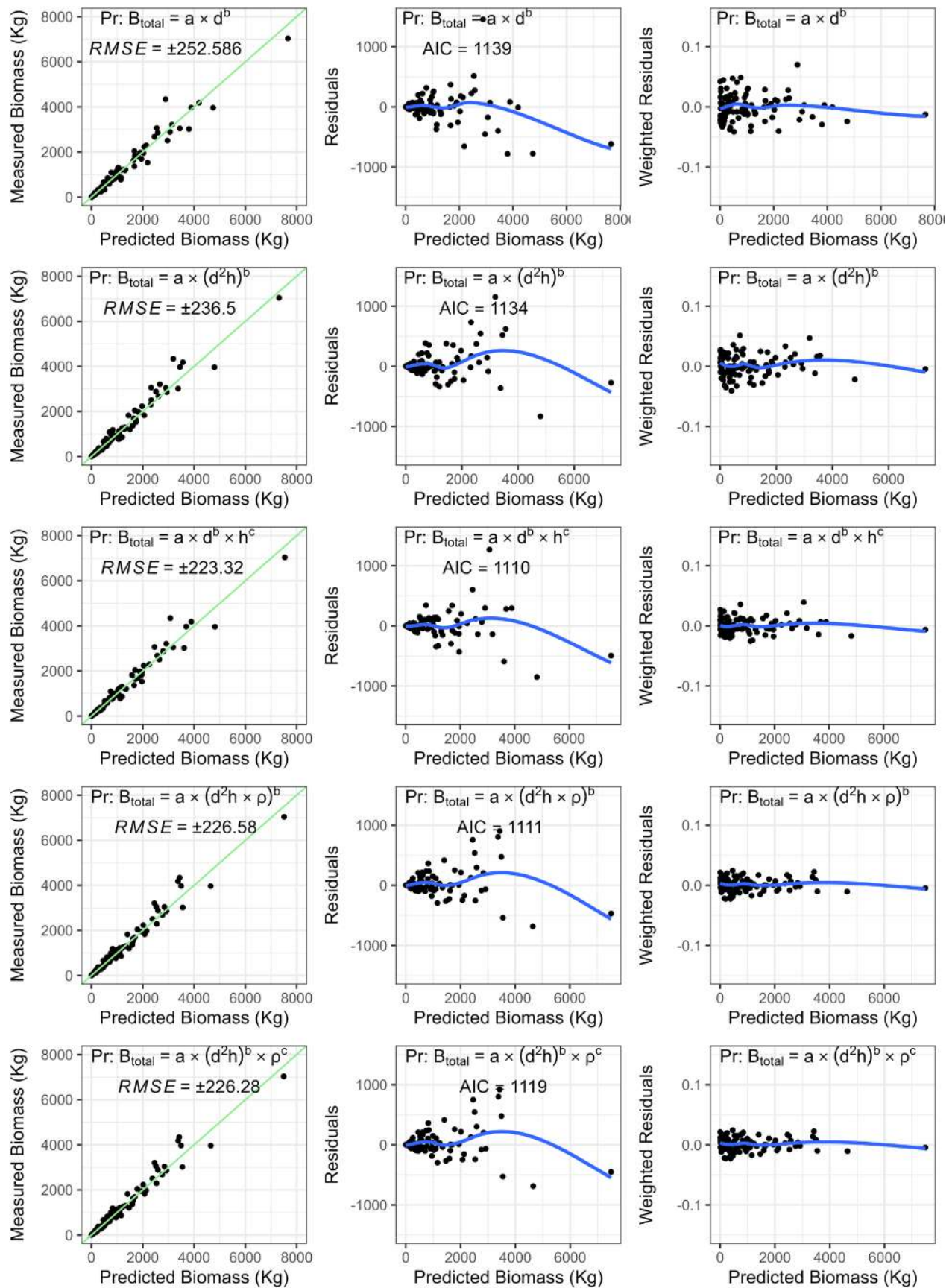
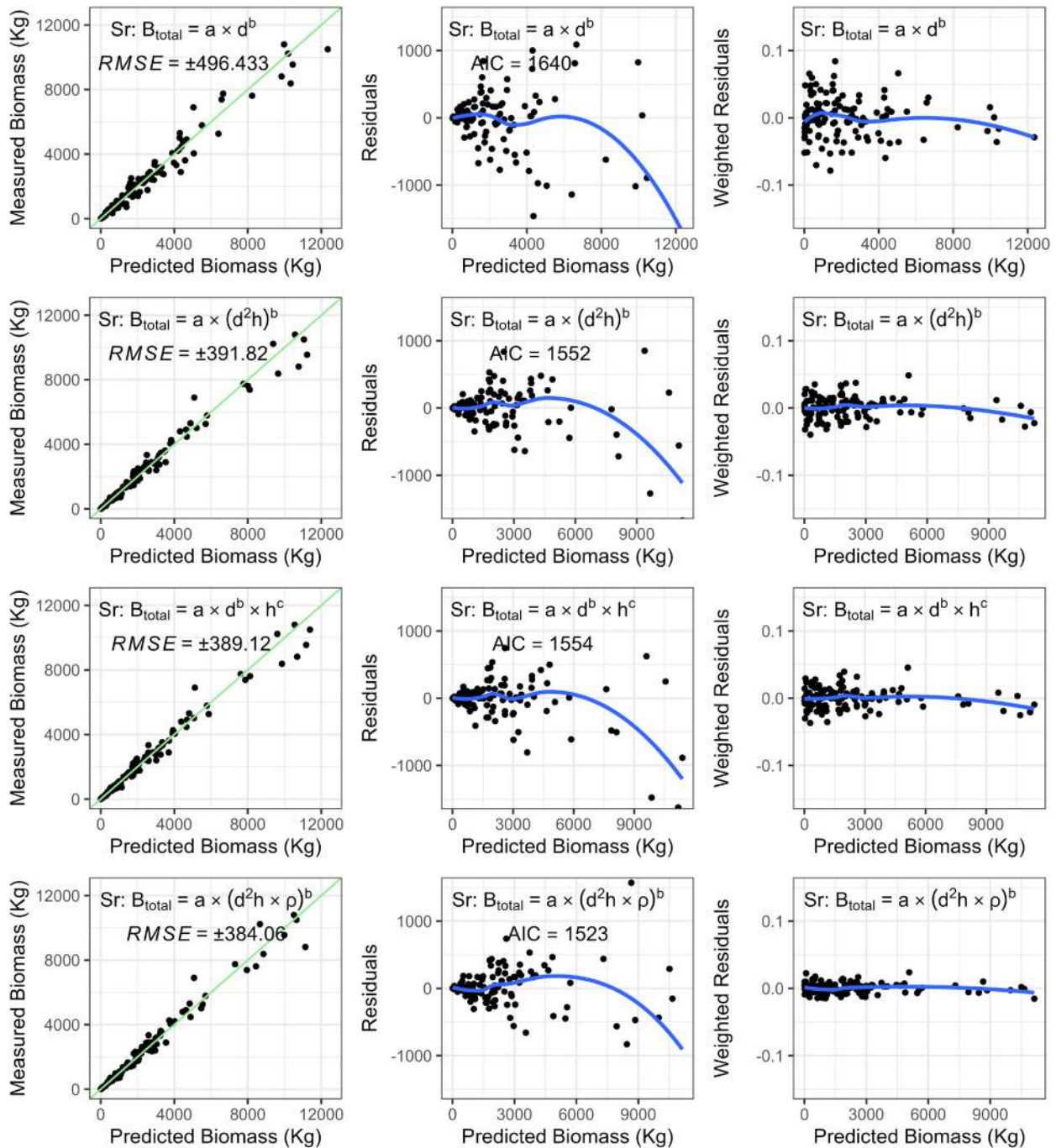


Figure A6.4: Shows the five model's performance for the total tree biomass of *Pinus roxburghii*, (a) shows the comparison between predicted and actual biomass, (b) displays the residuals against the predicted biomass, (c) shows the weighted residuals against predicted biomass. For tree code (An, Cs, Lp, Sw, Pr, Sr, Ta) refer Table 1.

Table A6.5: Summary of performance metrics for candidate models of *Shorea robusta* for total biomass. (All displayed parameters are significant at 5%).

Equation	n	w	a	b	c	AIC	RMSE	MB
$B = a \times d^b$	122	2.3908	0.075451	2.593664	-	1640.02	496.44	-39.99
$B = a \times d^{2h^b}$	122	2.4577	0.020267	1.031164	-	1552.4	391.82	-7.88
$B = a \times d^b \times h^c$	122	2.4693	0.025586	2.162449	0.843333	1554.13	389.12	-27.12
$B = a \times d^{2h^b}$	122	2.6255	0.054968	0.980885	-	1522.86	384.06	13.57
$B = a \times d^{2h^b} \times (\rho)^c$	122	2.6243	0.054299	0.981513	0.968941	1530.86	383.62	13.15



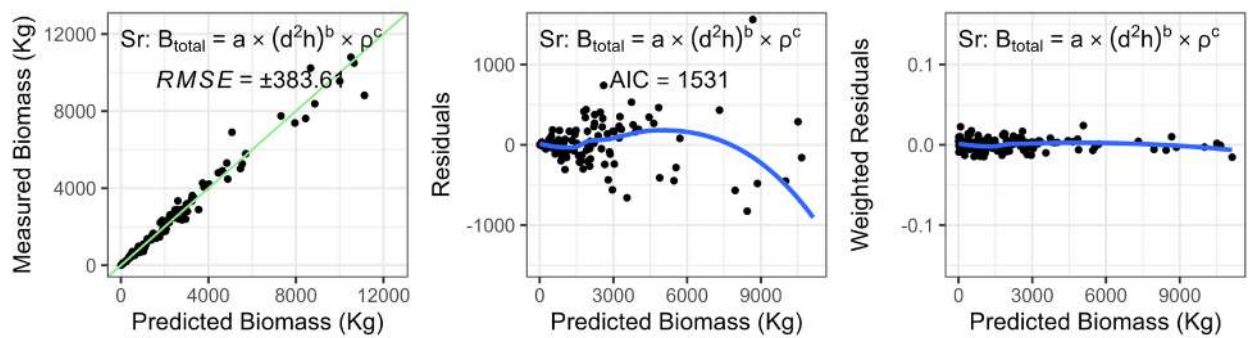
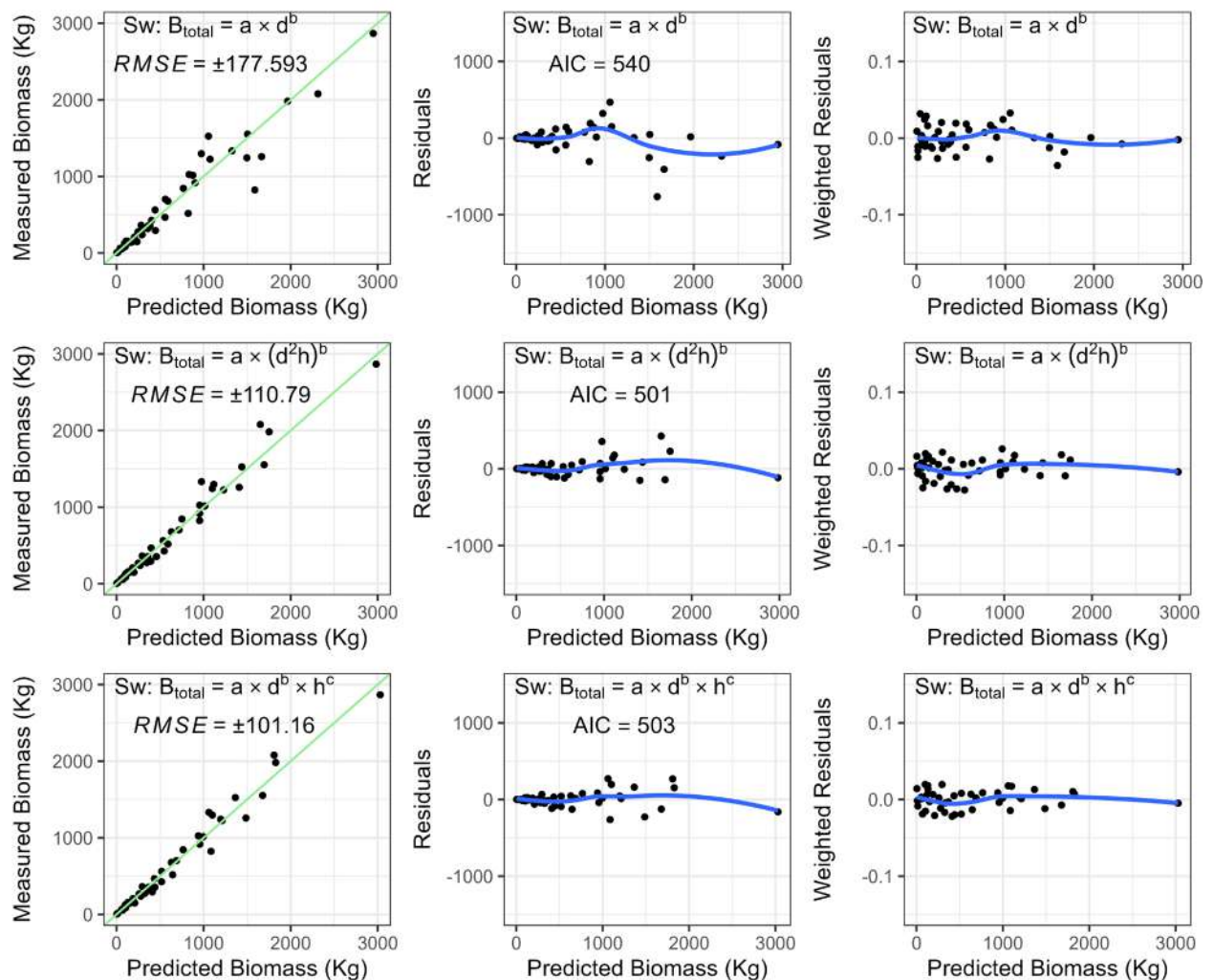


Figure A6.5: Shows the five model's performance for the total tree biomass of *Shorea robusta*, (a) shows the comparison between predicted and actual biomass, (b) displays the residuals against the predicted biomass, (c) shows the weighted residuals against predicted biomass. For tree code (An, Cs, Lp, Sw, Pr, Sr, Ta) refer Table 1.

Table A6.6: Summary of performance metrics for candidate models of *Schima wallichii*. for total biomass. (All displayed parameters are significant at 5%).

Equation	n	w	a	b	c	AIC	RMSE	MB
$B = a * d^b$	47	2.5108	0.061394	2.559158	-	539.57	177.6	-12.49
$B = a * d^2h^b$	47	2.4424	0.026367	0.981525	-	500.64	110.8	15.71
$B = a * d^b * ht^c$	47	2.4698	0.031461	2.101355	0.764732	503.25	101.16	3.06
$B = a * d^2hp^b$	47	2.3642	0.071359	0.951091	-	494.61	98.8	9.56
$B = a * d^2h^b * (\rho)^c$	47	2.3719	0.063804	0.954658	0.845437	502.51	99.53	9.91



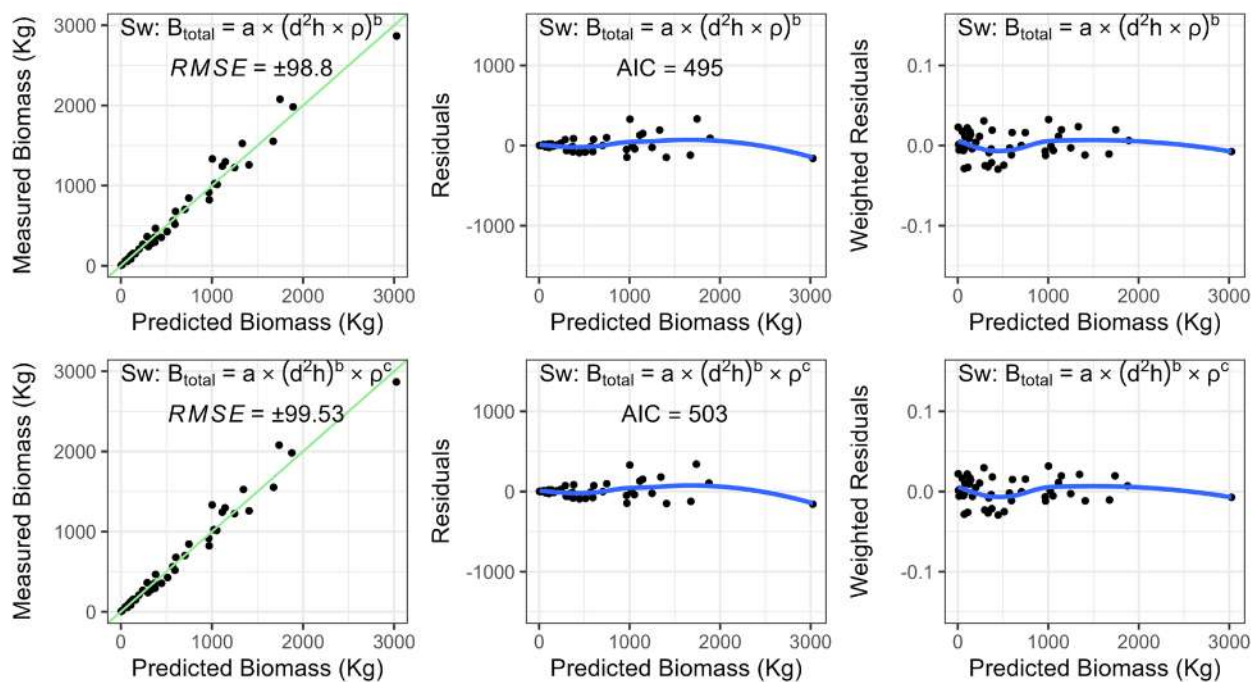
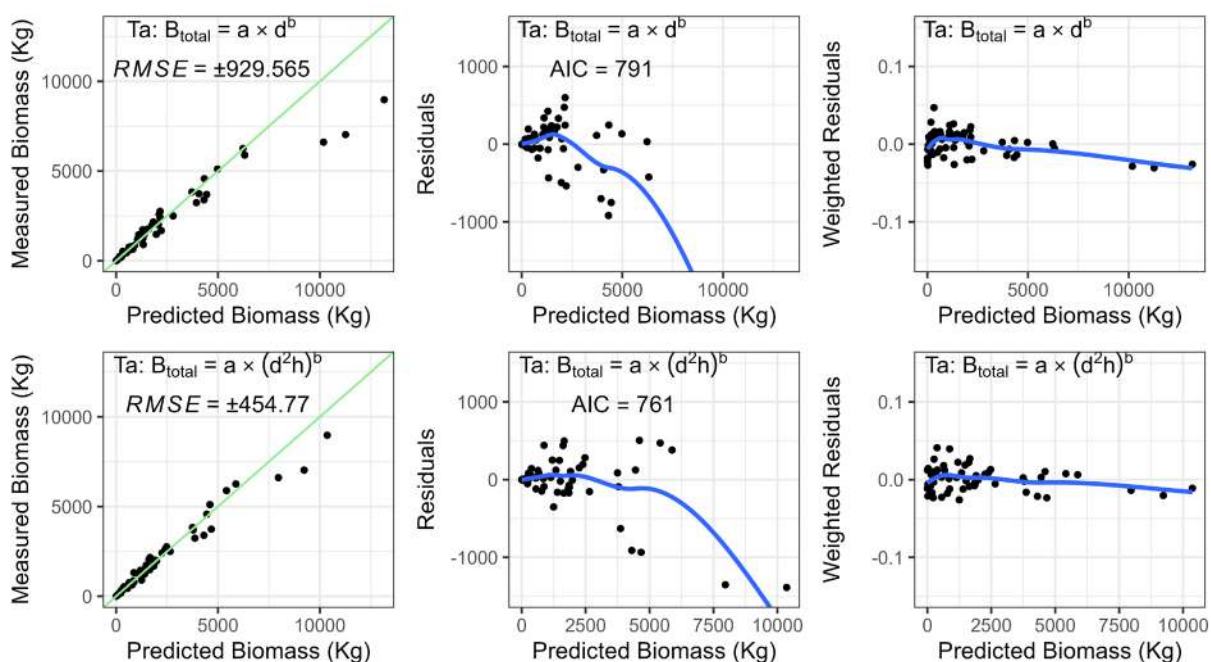


Figure A6.6: Shows the five model's performance for the total tree biomass of *Schima wallichii*, (a) shows the comparison between predicted and actual biomass, (b) displays the residuals against the predicted biomass, (c) shows the weighted residuals against predicted biomass. For tree code (An, Cs, Lp, Sw, Pr, Sr, Ta) refer Table 1.

Table A6.7: Summary of performance metrics for candidate models of *Terminalia alata*. for total biomass. (All displayed parameters are significant at 5%).

Equation	n	w	a	b	c	AIC	RMSE	MB
$B = a * d^b$	61	2.5867	0.076263	2.600663	-	790.82	929.57	-200.79
$B = a * d^{2h^b}$	61	2.5321	0.031871	0.989765	-	761.07	454.77	-72.14
$B = a * d^b * ht^c$	61	2.5604	0.034926	2.051212	0.879393	768.49	502.79	-92.18
$B = a * d^{2h}p^b$	61	2.7106	0.080156	0.943341	-	736.86	433.16	-71.49
$B = a * d^{2h} * (\rho)^c$	61	2.7127	0.091024	0.936493	1.066771	744.43	429.72	-67.23



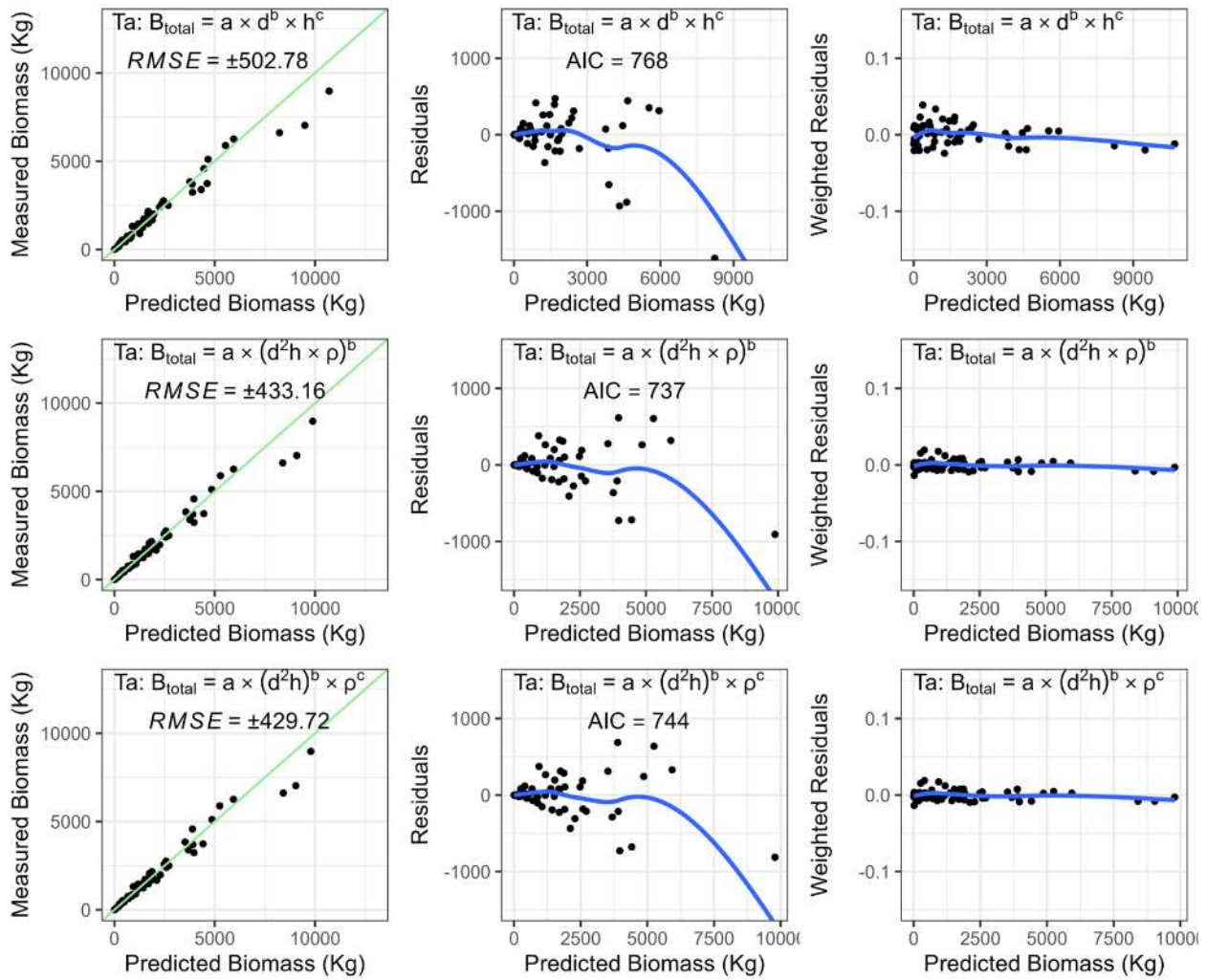


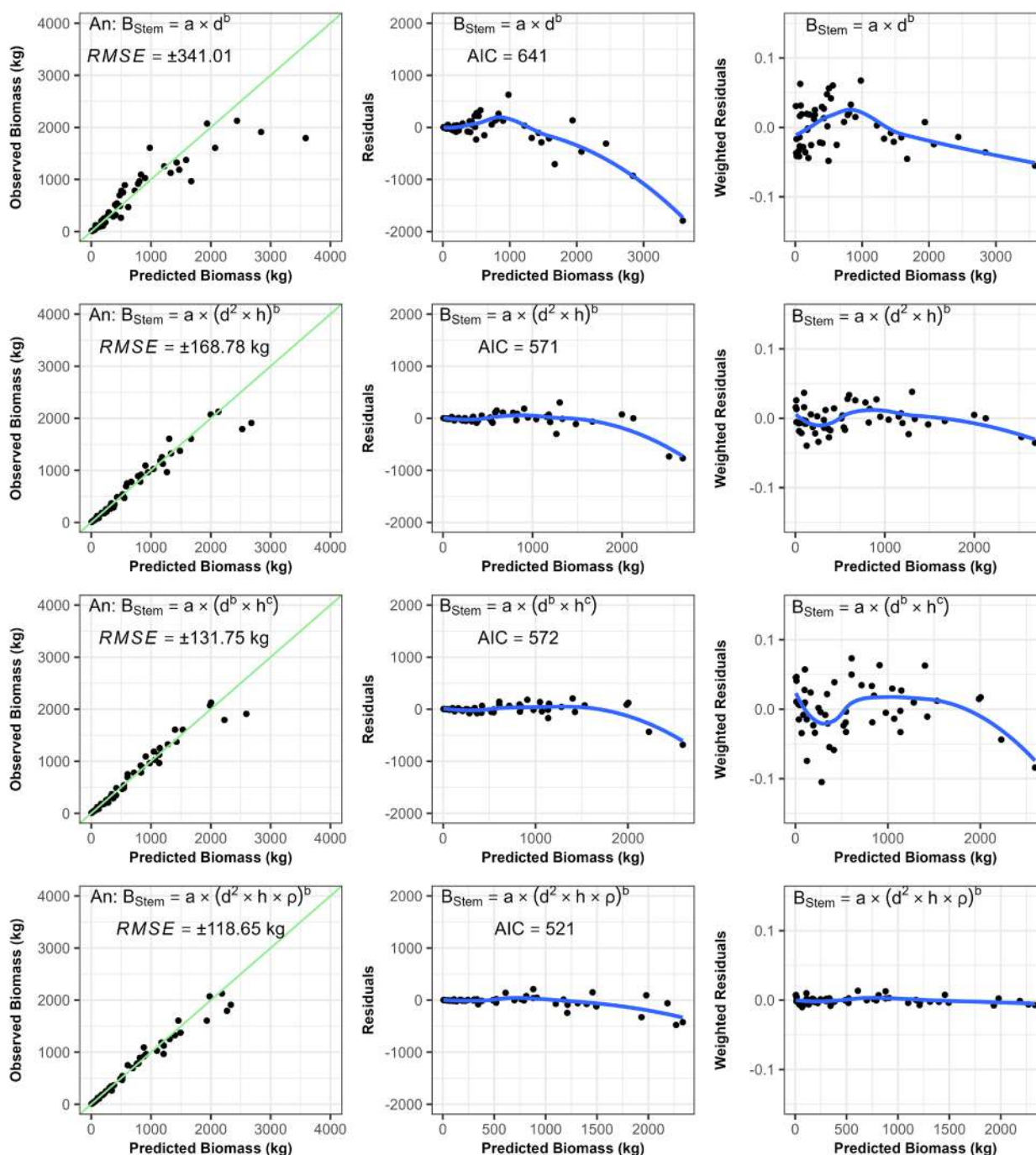
Figure A6.7: Shows the five model's performance for the total tree biomass of *Terminalia alata*, (a) shows the comparison between predicted and actual biomass, (b) displays the residuals against the predicted biomass, (c) shows the weighted residuals against predicted biomass For tree code (An, Cs, Lp, Sw, Pr, Sr, Ta) refer Table 1.

Annex VII

Summary of Stem Biomass Models

Table A7.1: Summary of performance metrics for candidate models of *Alnus nepalensis* for stem biomass. (All displayed parameters are significant at 5%).

Equation	n	w	a	b	c	AIC	RMSE	MB
$B = a \times d^b$	52	2.35	0.07	2.44	-	641.03	341.01	-52
$B = a \times d^2 h^b$	52	2.31	0.02	0.96	-	570.83	168.78	-25.3
$B = a \times d^b \times h^c$	52	2.08	0.01	1.78	1.28	571.57	131.75	-8.4
$B = a \times d^2 h^b$	52	2.54	0.060094	0.946166	-	521.15	118.6	-26.5
$B = a \times d^2 h^b \times (\rho)^c$	52	2.6	0.07	0.94	1.14	526.56	112.52	-25



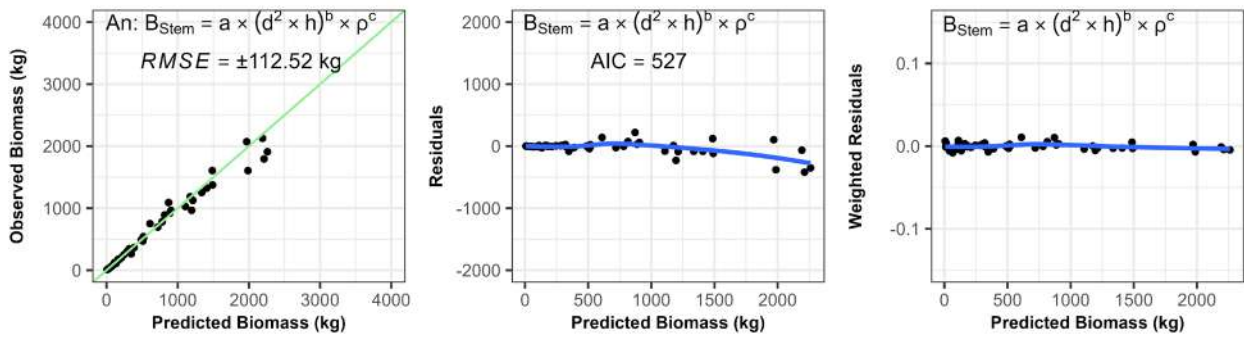
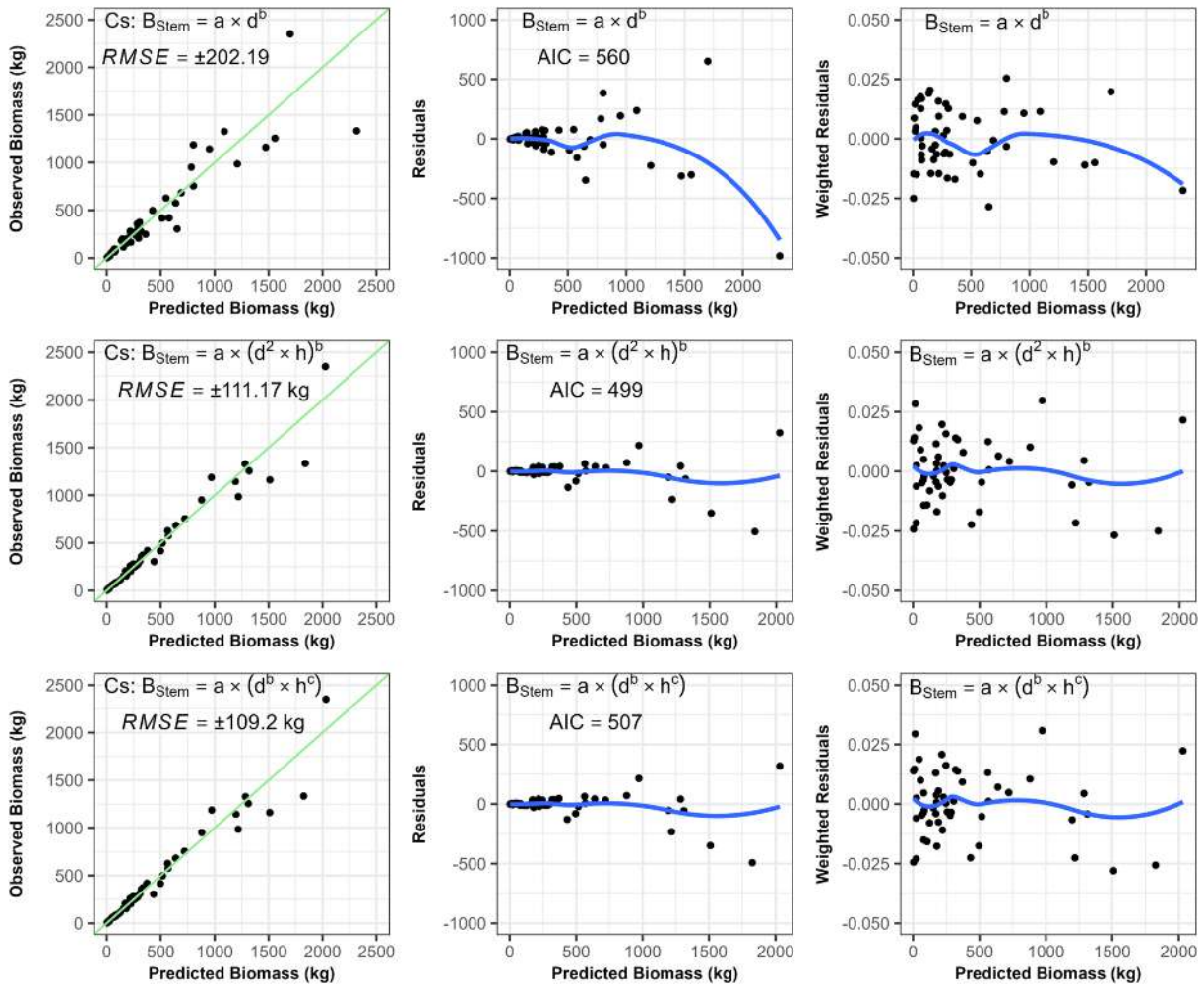


Figure A7.1 : Shows the five model's performance for the stem biomass of *Schima wallichii*, (a) shows the comparison between predicted and actual biomass, (b) displays the residuals against the predicted biomass, (c) shows the weighted residuals against predicted biomass. For tree code (An, Cs, Lp, Sw, Pr, Sr, Ta) refer Table 1.

Table A7.2: Summary of performance metrics for candidate models of *Castanopsis* spp. for stem biomass. (All displayed parameters are significant at 5%).

Equation	n	w	a	b	c	AIC	RMSE	MB
$B = a * d^b$	52	2.47	0.07	2.39	-	560.19	202.19	-15.4
$B = a * d^2 h^b$	52	2.29	0.03	0.96	-	499.17	111.17	-9.7
$B = a * d^b * h^c$	52	2.27	0.02	1.9	0.98	507.11	109.2	-9.1
$B = a * d^2 h^b$	52	2.46	0.062227	0.93304	-	495.57	109.7	-9.8
$B = a * d^2 h^b * (\rho)^c$	52	2.39	0.04	0.94	0.53	497.77	109.19	-11.2



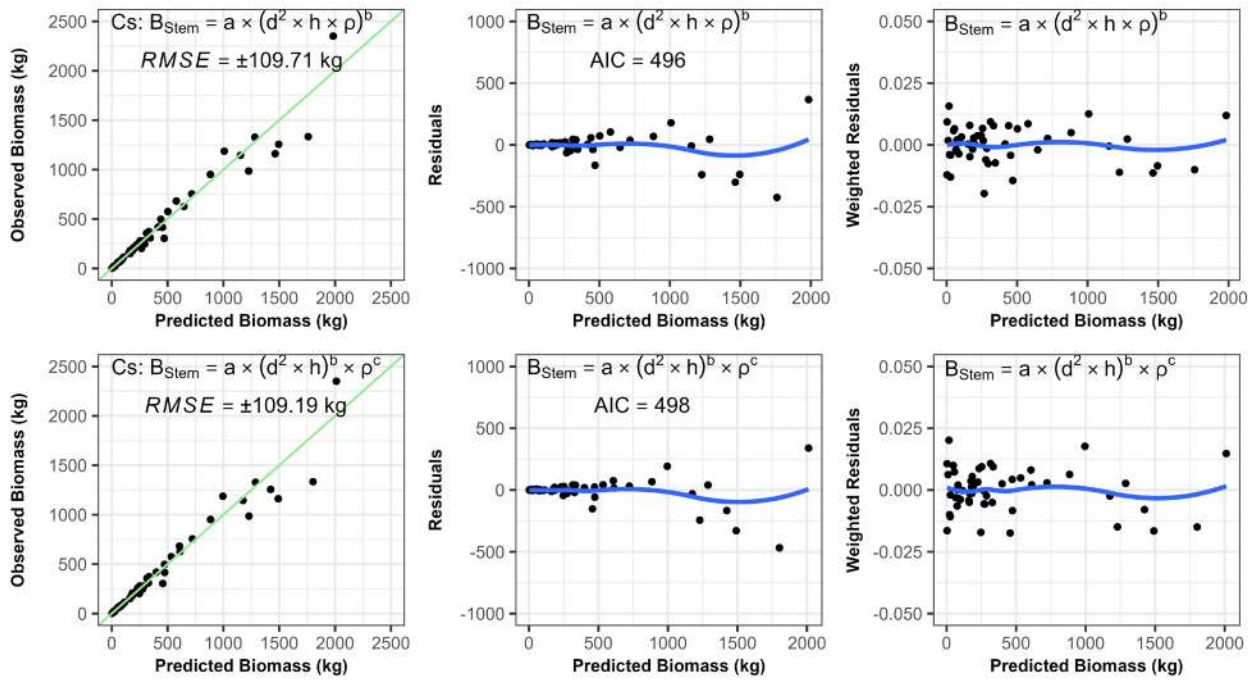
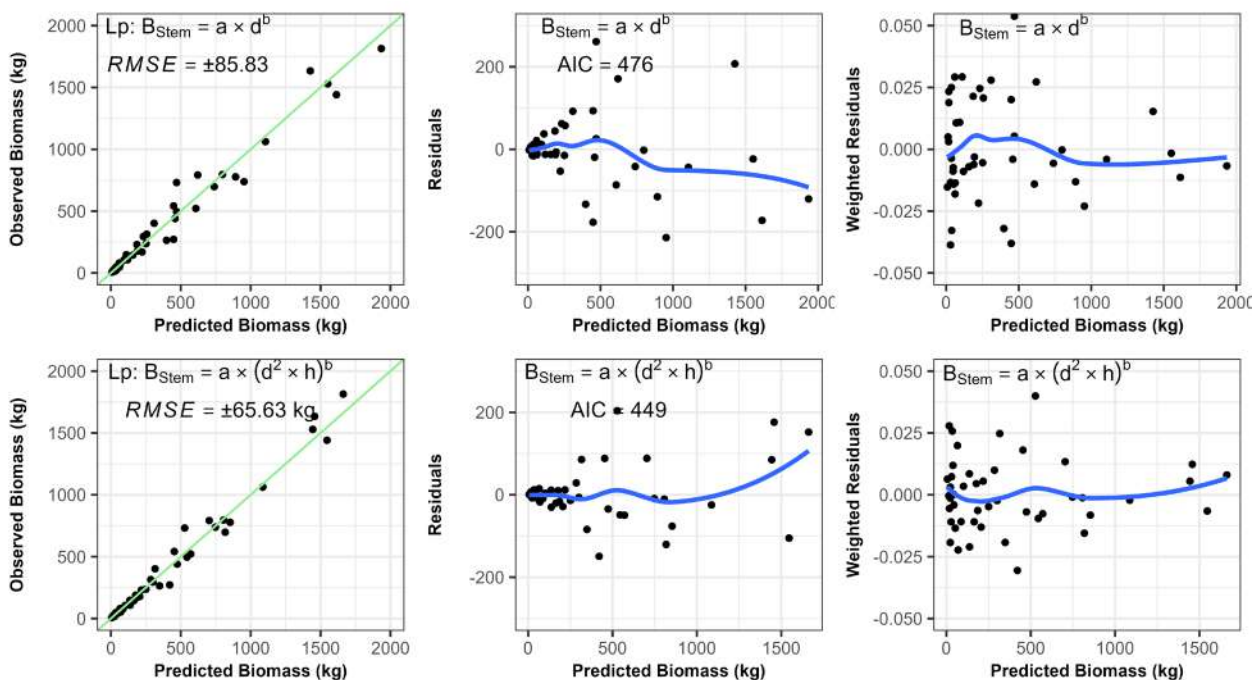


Figure A7.2: Shows the five model's performance for the stem biomass of *Castanopsis* spp, (a) shows the comparison between predicted and actual biomass, (b) displays the residuals against the predicted biomass, (c) shows the weighted residuals against predicted biomass. For tree code (An, Cs, Lp, Sw, Pr, Sr, Ta) refer Table 1.

Table A7.3: Summary of performance metrics for candidate models of *Lagerstroemia parviflora* for stem biomass. (All displayed parameters are significant at 5%).

Equation	n	w	a	b	c	AIC	RMSE	MB
$B = a * d^b$	46	2.41	0.05	2.61	-	475.65	85.83	-4.9
$B = a * d^2 h^b$	46	2.42	0.02	0.99	-	448.56	65.63	2.5
$B = a * d^b * h^c$	46	2.42	0.02	1.97	1	456.56	65.72	2.7
$B = a * d^2 h^b$	46	2.59	0.05921	0.941559	-	421.57	61.6	3.3
$B = a * d^2 h^b * (\rho)^c$	46	2.59	0.06	0.94	0.97	429.54	61.7	3.4



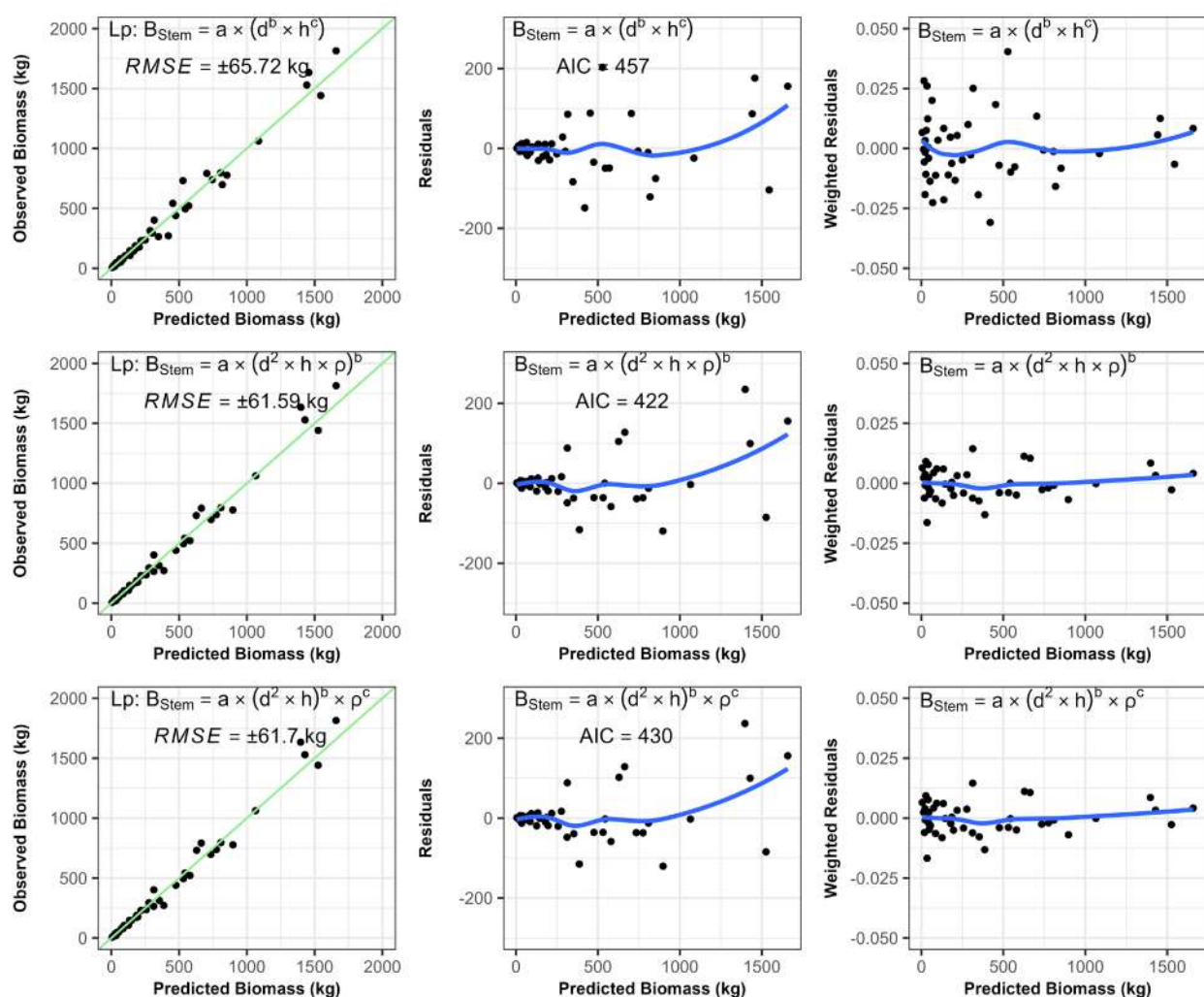


Figure A7.3: Shows the five model's performance for the stem biomass of *Lagerstroemia parviflora*, (a) shows the comparison between predicted and actual biomass, (b) displays the residuals against the predicted biomass, (c) shows the weighted residuals against predicted biomass. For tree code (An, Cs, Lp, Sw, Pr, Sr, Ta) refer Table 1.

Table A7.4: Summary of performance metrics for candidate models of *Pinus roxburghii* for stem biomass. (All displayed parameters are significant at 5%).

Equation	n	w	a	b	c	AIC	RMSE	MB
$B = a * d^b$	96	2.38	0.03	2.73	-	1125.42	211.15	-7.9
$B = a * d^2 h^b$	96	2.33	0.01	1.02	-	1034.03	152.85	2.6
$B = a * d^b * h^c$	96	2.35	0.02	2.08	0.96	1041.47	153.53	0.7
$B = a * d^2 h^b$	96	2.5	0.054893	0.960175	-	952.22	136.7	-2.1
$B = a * d^2 h^b * (\rho)^c$	96	2.49	0.07	0.95	1.21	953.53	139.28	-2.7

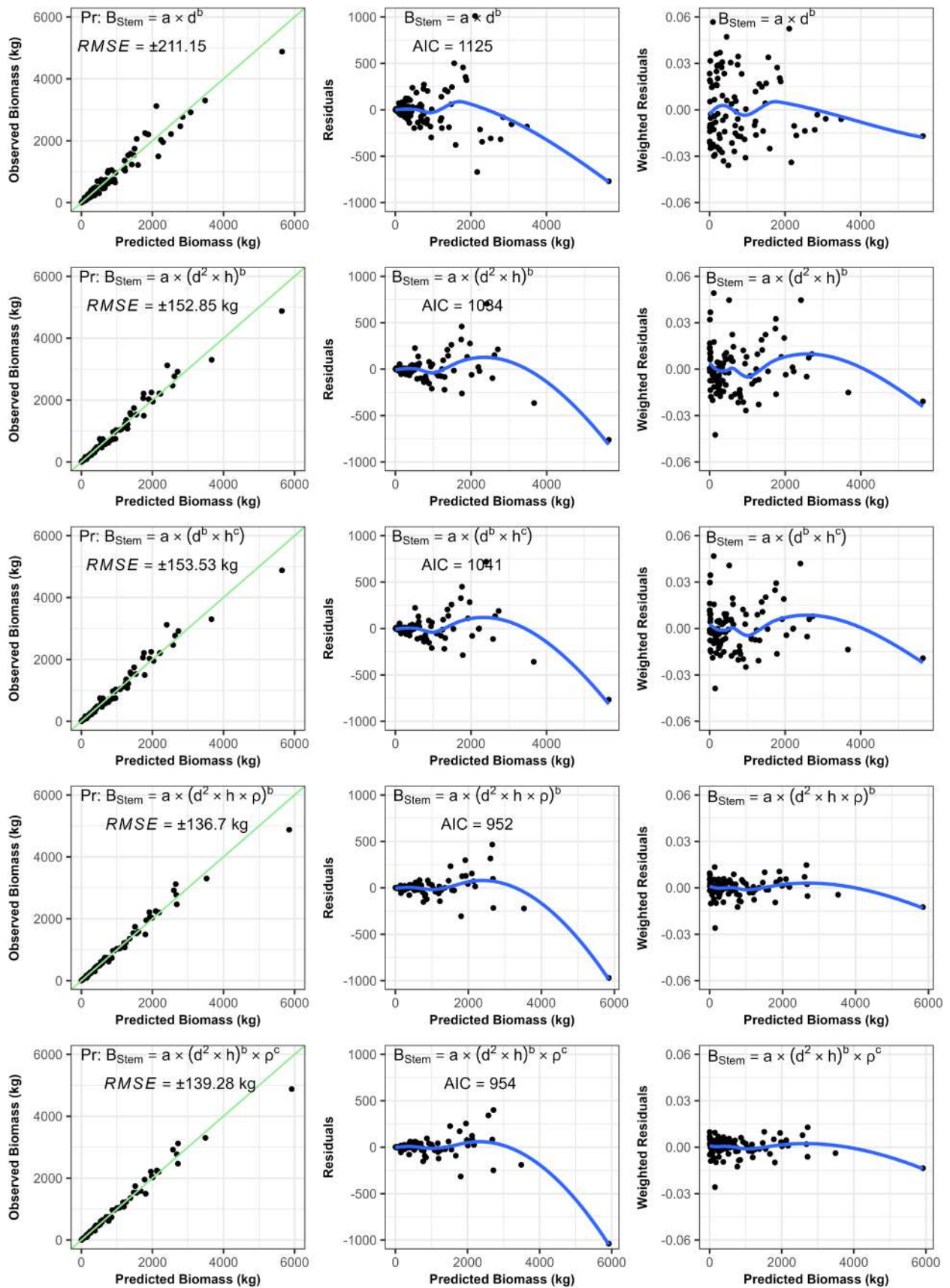
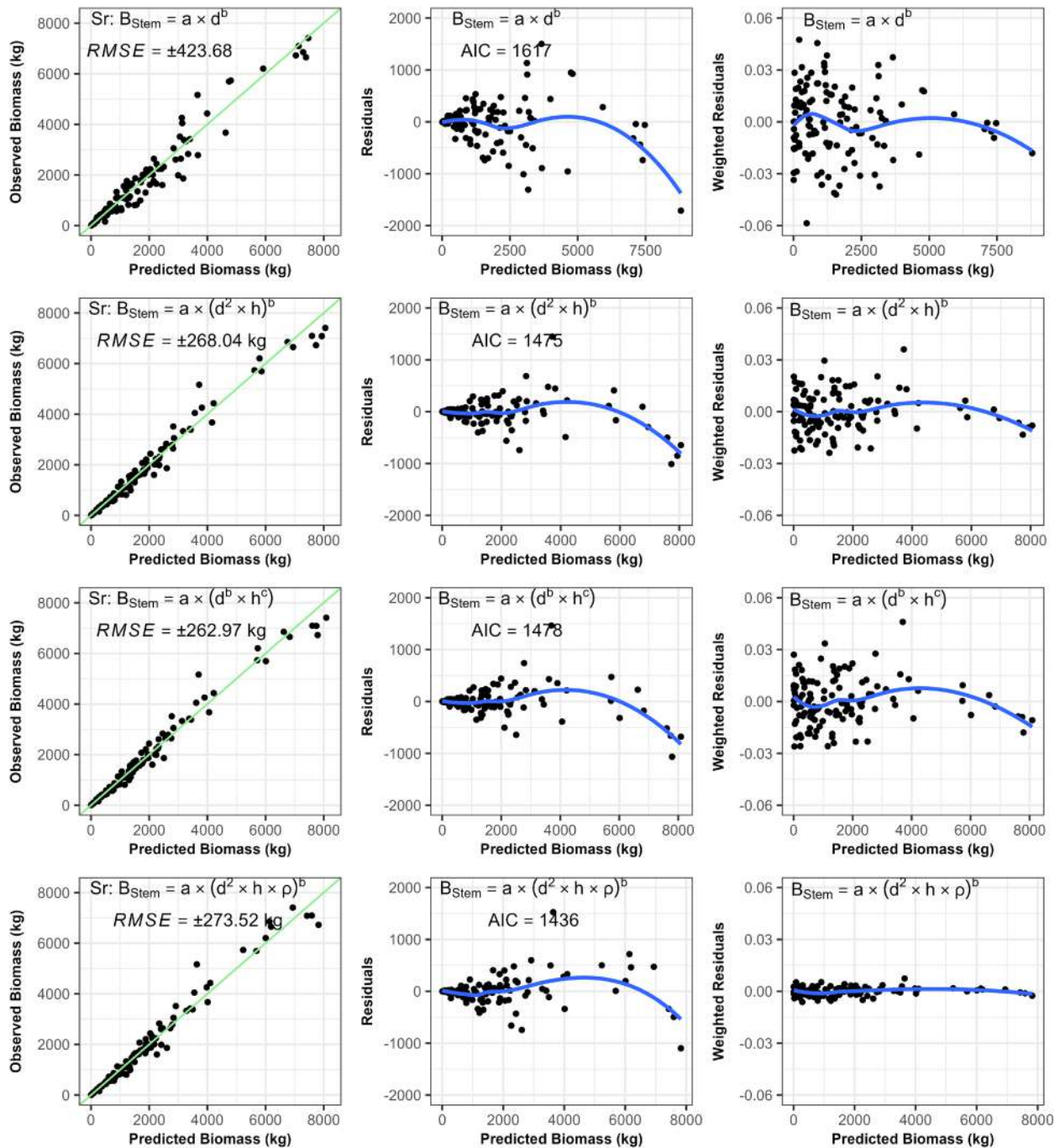


Figure A7.4: Shows the five model's performance for the stem biomass of *Pinus roxburghii*, (a) shows the comparison between predicted and actual biomass, (b) displays the residuals against the predicted biomass, (c) shows the weighted residuals against predicted biomass. For tree code (An, Cs, Lp, Sw, Pr, Sr, Ta) refer Table 1.

Table A7.5: Summary of performance metrics for candidate models of *Shorea robusta* for stem biomass. (All displayed parameters are significant at 5%).

Equation	n	W	a	b	c	AIC	RMSE	MB
$B = a \times d^b$	122	2.48	0.07	2.54	-	1617.27	423.68	-27.4
$B = a \times d^2 h^b$	122	2.47	0.02	1.01	-	1474.92	268.04	-16.5
$B = a \times d^b \times h^c$	122	2.42	0.02	1.93	1.17	1478.38	262.97	-5.5
$B = a \times d^2 h^b$	122	2.86	0.056689	0.94976	-	1436.34	273.5	10.6
$B = a \times d^2 h^b \times (\rho)^c$	122	2.89	0.06	0.94	1.05	1443.77	279.53	14.4



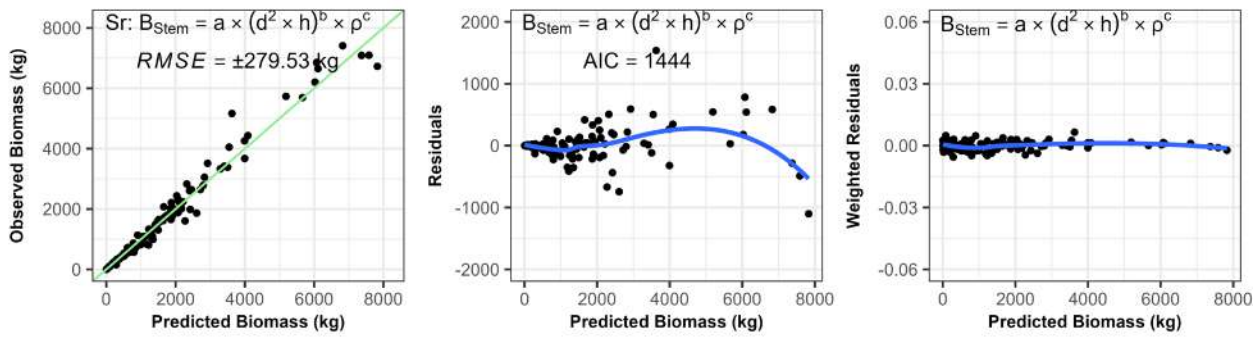
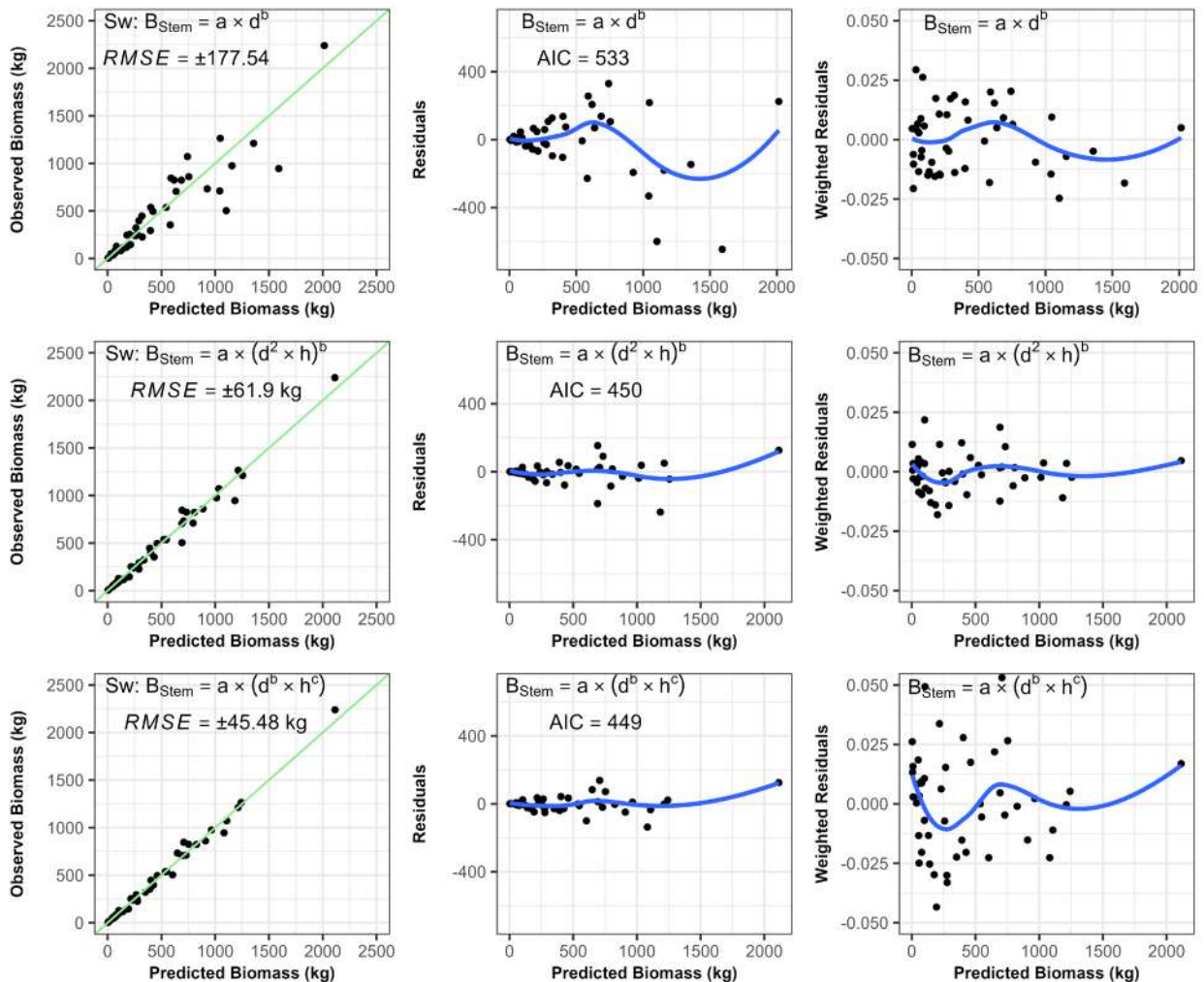


Figure A7.5: Shows the five model's performance for the stem biomass of *Shorea robusta*, (a) shows the comparison between predicted and actual biomass, (b) displays the residuals against the predicted biomass, (c) shows the weighted residuals against predicted biomass. For tree code (An, Cs, Lp, Sw, Pr, Sr, Ta) refer Table 1.

TableA7.6: Summary of performance metrics for candidate models of *Schima wallichii* for stem biomass. (All displayed parameters are significant at 5%).

Equation	n	w	a	b	c	AIC	RMSE	MB
$B = a * d^b$	47	2.54	0.06	2.49	-	532.77	177.54	-13.8
$B = a * d^{2h^b}$	47	2.42	0.02	0.96	-	449.81	61.9	-6.5
$B = a * d^b * ht^c$	47	2.11	0.017416	1.793677	1.210074	448.73	45.5	-0.3
$B = a * d^{2h^b}$	47	2.42	0.06	0.93	-	451.11	68.71	-8.6
$B = a * d^{2h^b} * (\rho)^c$	47	2.43	0.04	0.95	0.41	455.36	63.91	-7.9



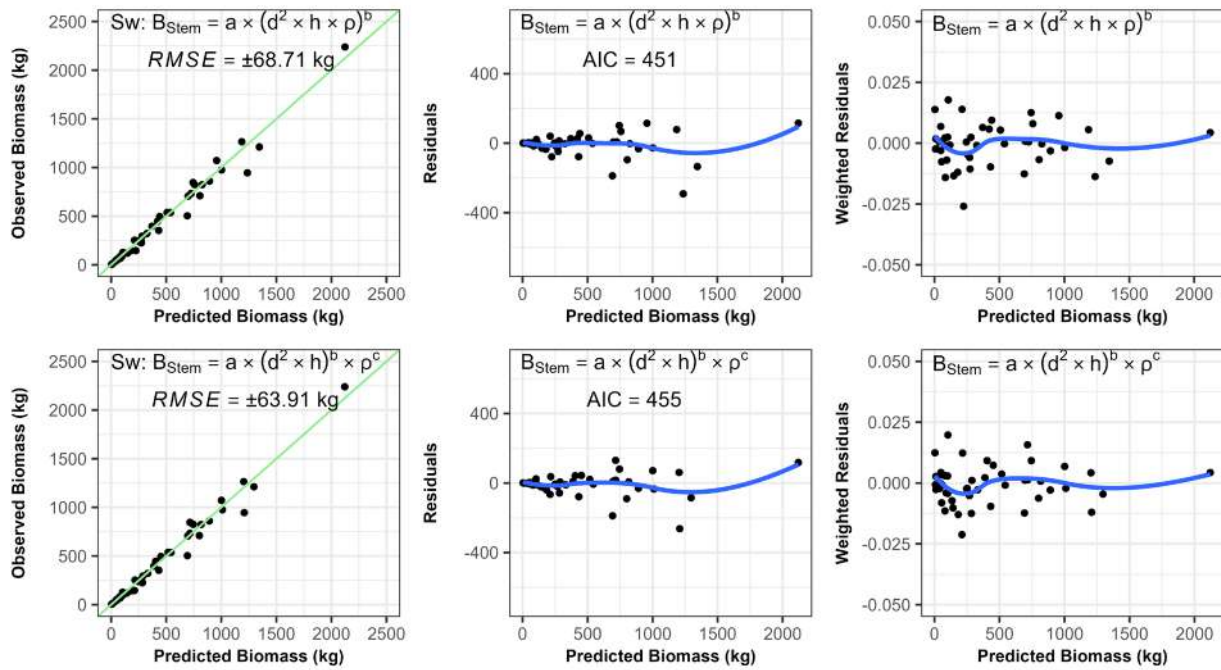
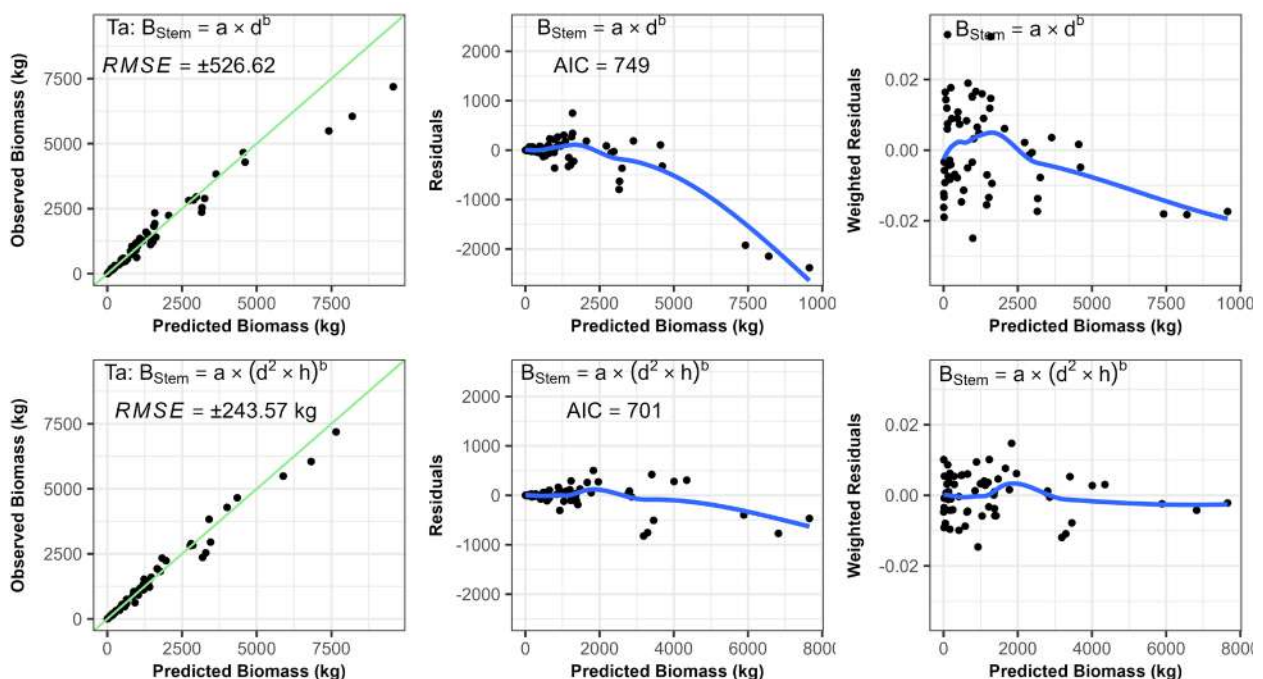


Figure A7.6: Shows the five model's performance for the stem biomass of *Schima wallichii*, (a) shows the comparison between predicted and actual biomass, (b) displays the residuals against the predicted biomass, (c) shows the weighted residuals against predicted biomass. For tree code (An, Cs, Lp, Sw, Pr, Sr, Ta) refer Table 1.

Table A7.7: Summary of performance metrics for candidate models of *Terminalia alata* for stem biomass. (All displayed parameters are significant at 5%).

Equation	n	w	a	b	c	AIC	RMSE	MB
$B = a * d^b$	61	2.55	0.06	2.58	-	748.62	526.62	-105.9
$B = a * d^2 h^b$	61	2.65	0.02	0.99	-	700.78	243.57	-25.6
$B = a * d^b * h^c$	61	2.65	0.02	1.97	1	708.78	242.35	-24.6
$B = a * d^2 h^b$	61	2.71	0.064566	0.934114	-	659.71	186.8	-12.4
$B = a * d^2 h^b * (\rho)^c$	61	2.68	0.07	0.93	1.04	667.07	184.79	-9.3



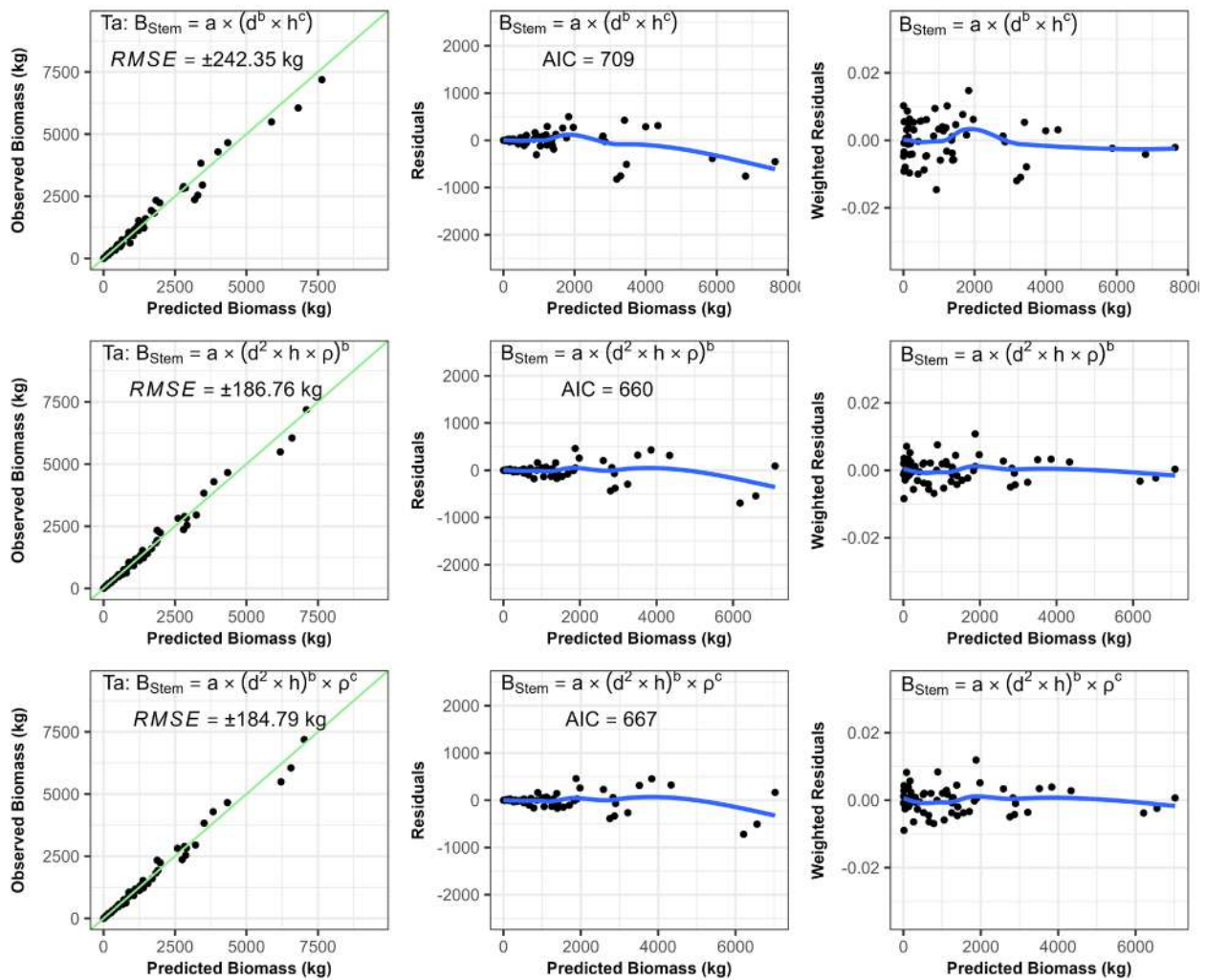


Figure A7.7: Shows the five model's performance for the stem biomass of *Terminalia alata*, (a) shows the comparison between predicted and actual biomass, (b) displays the residuals against the predicted biomass, (c) shows the weighted residuals against predicted biomass. For tree code (An, Cs, Lp, Sw, Pr, Sr, Ta) refer Table 1.

Annex VIII

Biomass (Oven Dry) and Volume Conversion Factors

Table A8.1: Volume Ratio (Large branch to stem)

Dia Class	05–30					30–50					50 Above				
Species	N	min	mean	max	sd	N	min	mean	max	sd	N	min	mean	max	sd
An	23	0	0.01	0.10	0.02	18	0.00	0.05	0.15	0.05	11	0.02	0.18	0.51	0.13
Cs	26	0	0.06	0.48	0.12	19	0.03	0.32	0.92	0.23	7	0.20	0.52	1.19	0.34
Lp	29	0	0.02	0.23	0.05	13	0.03	0.18	0.43	0.11	4	0.00	0.06	0.13	0.06
Pr	39	0	0.01	0.43	0.07	33	0.00	0.05	0.37	0.09	24	0.00	0.14	0.35	0.10
Sr	31	0	0.01	0.17	0.04	42	0.00	0.14	0.58	0.12	49	0.00	0.24	0.74	0.15
Sw	24	0	0.04	0.31	0.09	16	0.00	0.10	0.27	0.08	7	0.03	0.32	0.78	0.25
Ta	22	0	0.05	0.27	0.08	21	0.02	0.18	0.38	0.10	18	0.04	0.19	0.60	0.13

Note: The stem and large branch includes the size up to top 10 cm over bark diameter while volume indicates the under bark volume.

Table A8.2: Biomass Ratio (Branch to stem)

Dia Class	05-30					30-50					50 Above				
Species	N	min	mean	max	sd	N	min	mean	max	sd	N	min	mean	max	sd
An	23	0	0.08	0.44	0.11	18	0.03	0.25	0.55	0.14	11	0.05	0.18	0.27	0.08
Cs	26	0	0.35	1.07	0.33	19	0.24	0.51	1.03	0.24	7	0.13	0.31	0.46	0.14
Lp	29	0	0.19	0.54	0.15	13	0.10	0.33	0.65	0.14	4	0.05	0.15	0.21	0.07
Pr	39	0	0.11	0.79	0.19	33	0.04	0.35	0.90	0.22	24	0.05	0.22	0.70	0.13
Sr	31	0	0.14	0.83	0.18	42	0	0.22	0.85	0.15	49	0.04	0.17	0.46	0.10
Sw	24	0	0.15	0.49	0.16	16	0.08	0.30	0.63	0.16	7	0.09	0.25	0.39	0.10
Ta	22	0	0.16	0.56	0.16	21	0	0.23	0.46	0.09	18	0.04	0.13	0.41	0.08

Note: Branch diameter 4.5 to 10 cm (over bark)

Table A8.3: Biomass Ratio (Branch to stem)

Dia Class	05-30					30-50					50 Above				
Species	N	min	mean	max	sd	N	min	mean	max	sd	N	min	mean	max	sd
An	23	0.02	0.20	0.59	0.16	18	0.03	0.19	0.45	0.09	11	0.03	0.13	0.20	0.06
Cs	26	0.11	0.48	1.14	0.29	19	0.16	0.42	0.88	0.20	7	0.09	0.23	0.43	0.12
Lp	29	0.06	0.22	0.45	0.10	13	0.09	0.24	0.43	0.09	4	0.05	0.10	0.15	0.04
Pr	39	0.04	0.25	0.75	0.17	33	0.09	0.28	0.73	0.15	24	0.03	0.17	0.56	0.11
Sr	31	0.00	0.15	0.54	0.11	42	0.00	0.18	0.55	0.10	49	0.04	0.13	0.37	0.08
Sw	24	0.08	0.25	0.54	0.14	16	0.05	0.24	0.41	0.10	7	0.07	0.20	0.35	0.09
Ta	22	0.02	0.21	0.49	0.12	21	0.00	0.17	0.34	0.07	18	0.04	0.10	0.24	0.05

Note: Branch diameter <10 cm (over bark)

Table A8.4: Biomass Expansion Factor (Stem to total woody biomass)

Dia Class	05-30					30-50					50 Above				
Species	N	min	mean	max	sd	N	min	mean	max	sd	N	min	mean	max	sd
An	23	1.02	1.20	1.69	0.17	18	1.04	1.24	1.61	0.12	11	1.05	1.34	1.80	0.20
Cs	26	1.11	1.53	2.59	0.36	19	1.30	1.75	2.89	0.39	7	1.32	1.78	2.65	0.45
Lp	29	1.06	1.24	1.45	0.12	13	1.19	1.42	1.68	0.17	4	1.06	1.22	1.34	0.12
Pr	39	1.04	1.27	1.75	0.18	33	1.09	1.33	1.73	0.18	24	1.11	1.31	1.60	0.14
Sr	31	1.00	1.16	1.54	0.13	42	1.04	1.32	2.13	0.19	49	1.16	1.39	2.14	0.21
Sw	24	1.08	1.29	1.73	0.18	16	1.06	1.35	1.65	0.15	7	1.18	1.53	2.17	0.35
Ta	22	1.06	1.25	1.66	0.17	21	1.16	1.35	1.70	0.12	18	1.10	1.30	1.78	0.17

Photo Plates



Tree Selection and marking



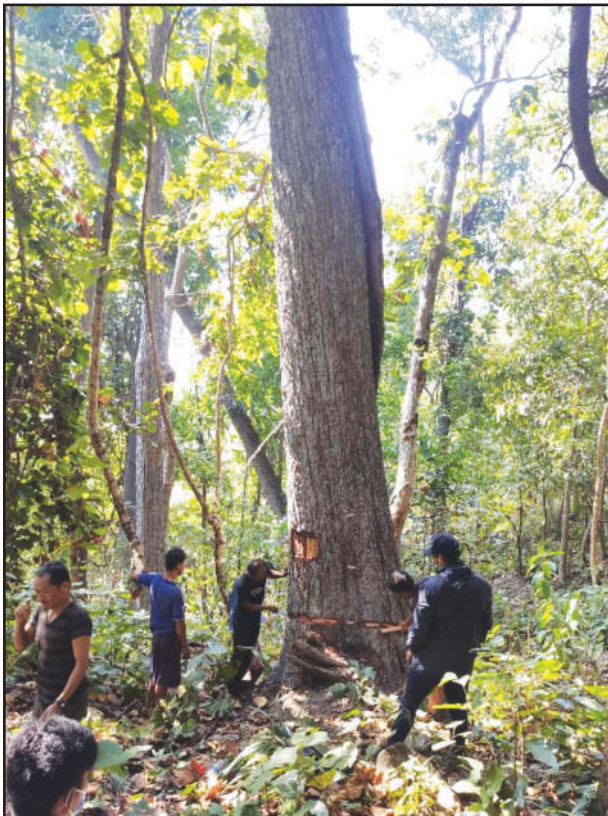
Stamping of sample trees



Measuring slope and aspect of site



Inventory of the plot



Marking on 0.3, 0.8, 1.3 m before felling tree

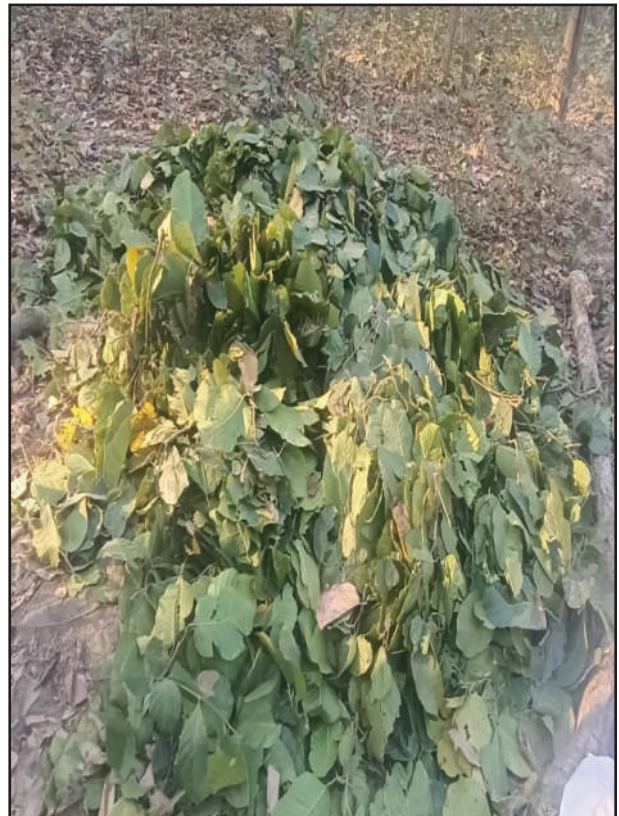




Tree feeling and stem profiling



Leaf plucking



Leaf collection



Preparation of disc



Weighing of disc



Volume measurement



Marking and measuring of top 10 cm diameter



Weighing of branches



Log management in field



Preparing air dry in Klin



Sample oven dry in klin



Data checking



Validation



Government of Nepal
Ministry of Forests and Environment
Forest Research and Training Centre
Kathmandu, Nepal

