Region-specific average wood densities of selected tree species of Bhutan and their comparison with the global database

.

ABSTRACT

|  |
| --- |
| **Aims:** The study was conducted to analyze the wood density for three conifer tree species (*Juniperus recurva*, *Picea spinulosa,* and *Abies densa)* which arewidely used in Bhutan for house construction, incense making and firewood purposes. The wood density for these species is exhibited according to physiographic regions of the country (West, West-Central, East, and East-Central). **Study design:** This study investigates the wood density of *Juniperus recurva*, *Abies densa*, and *Picea spinulosa* across Bhutan's physiographic zones. A total of 32 trees per species were sampled, with eight trees selected per zone. Due to its limited distribution, *Picea spinulosa* was sampled from only three zones. Sampling was stratified across different physiological conditions, with trees classified into eight diameter classes and four crown categories. Destructive randomized branch sampling (RBS) was employed, wherein trees were felled to extract stem disc samples at four positions along the main bole. Standard measurements of tree height, stump height, and basal diameter were recorded. Samples were dried in an oven at 80°C until a constant dry weight was achieved. Wood density was determined using the ratio of dry mass to green volume, with the latter measured via the water displacement method. This methodological approach ensures accurate wood property quantification, providing valuable insights into species-specific density variations.**Place and Duration of Study:** The study was conducted across Bhutan’s four physiographic zones, covering a range of environmental conditions to ensure comprehensive regional representation. Field sampling took place over multiple locations where *Juniperus recurva*, *Abies densa*, and *Picea spinulosa* are naturally distributed. **Methodology:** This study was conducted across four physiographic zones of Bhutan—western, west-central, east-central, and eastern—at elevations ranging from 2800 to 5000 meters above sea level to capture regional variations in wood density. Sample collection focused on three conifer species: *Juniperus recurva*, *Picea spinulosa*, and *Abies densa*. A total of 96 trees (32 per species) were sampled, with trees categorized into eight diameter classes and four crown classifications to ensure a representative dataset. Destructive randomized branch sampling (RBS) was employed, involving tree felling and extraction of stem disc samples from different height strata of the main bole. Fresh samples were labeled, cleaned, and transported to the laboratory for analysis following standardized protocols.In the laboratory, the green volume of each wood sample was determined using the water displacement method, while the dry mass was recorded after oven-drying the samples at 80°C until a constant weight was achieved. Basic wood density was calculated as the ratio of dry mass (g) to green volume (cm³). The density values were analyzed across different physiographic zones to identify regional variations. Additionally, the results were compared with the Global Wood Density Database to assess differences between Bhutanese conifers and global averages. The findings provide baseline wood density values for these species, supporting sustainable forestry practices and contributing to ecological and climate-related research.**Results:** The analysis revealed significant variation in wood density across the different physiographic zones and conifer species. *Abies densa* exhibited the highest average wood density across all zones, with values ranging from 0.46 to 0.56 g/cm³. *Picea spinulosa* showed intermediate density values, ranging from 0.40 to 0.48 g/cm³, while *Juniperus recurva* had the lowest average density, between 0.34 and 0.42 g/cm³. Wood density generally increased with elevation, with the highest densities found in the eastern and west-central zones, which have higher altitudes and more challenging environmental conditions.When grouped by diameter classes, the data revealed that larger trees typically had higher wood densities than smaller trees within each species. Crown classification also played a role, with trees exhibiting a fuller canopy tending to have slightly higher density values than those with less developed crowns. The results also showed a notable difference between Bhutanese conifers and the global wood density averages, with *Abies densa* and *Picea spinulosa* having slightly higher densities compared to global values for similar species, while *Juniperus recurva* was comparable. These findings suggest that local environmental conditions in Bhutan, including altitude and climatic factors, contribute to variations in wood density, which could inform forest management and conservation strategies**Conclusion:** This study highlights the significant variation in wood density among Bhutanese conifers, with species such as *Abies densa* showing higher densities compared to *Picea spinulosa* and *Juniperus recurva*. Elevation and crown classification were key factors influencing wood density, with higher altitudes and fuller crowns generally associated with increased density. These findings contribute valuable insights into the wood properties of Bhutanese conifers, providing essential data for forest management and conservation strategies, as well as offering a comparative perspective against global wood density norms. |

***Keywords:*** *Juniperus recurva, Picea spinulosa, Abies densa, wood density, Bhutan*

1. INTRODUCTION

Wood density is a fundamental property that influences the mechanical strength, durability, and industrial applications of timber (1–3). It plays a crucial role in determining the structural integrity of wood, affecting its suitability for construction, furniture making and pulp production (4). Beyond its commercial significance, wood density is also a key parameter in ecological and climate-related studies, serving as an indicator of tree growth patterns, carbon sequestration potential and forest biomass (5,6). Given its broad applications, precise quantification of wood density is essential for sustainable forest management, forest product utilization, and scientific research (7,8).

Coniferous species dominate Bhutan’s temperate and subalpine forests, providing essential ecosystem services and economic resources (9). Among them, *Juniperus recurva* (Weeping Juniper), *Picea spinulosa* (Sikkim Spruce), and *Abies densa* (Bhutan Fir) are ecologically and economically important. These species are widely distributed across high-altitude forests and play a crucial role in maintaining forest structure, biodiversity, and watershed stability. They are also highly valued for their timber, which is used in construction, handicrafts, and religious purposes. However, the physical and mechanical properties of these species, particularly wood density, remain poorly documented.

Despite their ecological and commercial importance, studies on the wood density of Bhutanese conifers are limited. Most available wood property data come from international sources, which may not accurately represent local variations influenced by Bhutan’s unique climatic and topographical conditions. The absence of region-specific data poses challenges for forest resource management, sustainable utilization, and conservation planning. Establishing baseline wood density values for these species will contribute to improving forestry practices, optimizing wood processing techniques, and supporting research on dendrochronology and climate-growth relationships.

This study aims to quantify the wood density of *J. recurva, P. spinulosa,* and *A. densa* using a simple field-based method for rapid wood density estimation (10–13). By generating species-specific data, this research will provide valuable insights into the structural characteristics of Bhutanese conifers and contribute to the sustainable management of forest resources. The findings will serve as a reference for forestry professionals, researchers, and policymakers, facilitating informed decision-making in forest conservation and utilization.

2. material and methods

**2.1. Study Area**

Bhutan encompasses a wide range of altitudes from 150 meters above sea level (*masl*) in the Sub-tropical region in the south to over 7000 *masl* in the north. However, for this study, the area was confined to an altitude range of 2800 *masl* to 5000 *masl* owing to the distribution range of target species *Juniperus recurva*, *Picea spinulosa* and *Abies densa*. This study covers four different physiographic zones of Bhutan: the western (W), west-central (WC), east-central (EC), and eastern (E) (Figure 1). This approach was adopted to ensure the sampling was not biased and to provide a representation of the entire population across all eco-regions of the country.

**Figure 1. Study area map showing the physiographic zones**

**2.2. Sampling**

Samples of *Juniperus recurva* and *Abies densa* were collected from all four physiographic zones. In comparison, *Picea spinulosa* samples were gathered from three zones due to its scarce distribution in the eastern region. At least 32 trees per species were sampled, with eight trees per zone (Table 1). Sampling within each zone was dispersed across various physiological conditions to ensure regional representation. Trees were categorized into eight diameter classes (5-10 cm, 10.1-20 cm, 20.1-30 cm, 30.1-40 cm, 40.1-50 cm, 50.1-60 cm, 60.1-70 cm, and 70.1-100 cm) and four crown classifications (dominant, co-dominant, intermediate, and suppressed (14,15).

The study employed destructive randomized branch sampling (RBS), a direct method for estimating biomass by felling trees, collecting and weighing the biomass, regarded as the most reliable for wood density and above-ground biomass studies (16,17). Following existing RBS protocols (18–20), trees were felled, and four-disc samples were extracted from the main boles (21). Measurements of tree height, stump height, and ground basal diameter were recorded, with the bole divided into two strata at one-third of the total tree height.

**2.3. Laboratory procedures**

All labeled fresh samples of the stem discs collected from the field were cleaned before being dried in an automatic electronic oven at 80°C for three days. Starting from the fourth day, the dry weight of the samples was recorded periodically until a constant dry weight was achieved. A digital balance with a precision level of up to 1 gram was used for the dry weight measurements. The species-specific basic wood density was determined by calculating the ratio of the constant dry mass to the green volume of each wood sample disc (22). The dry mass, measured in grams (g), was obtained after the samples were dried to a constant weight in an oven at 80°C. The green volume, measured in cubic centimeters (cm³), was determined by the water displacement method, which involves submerging the wood sample in water and measuring the displaced volume (13,23). This method ensures an accurate determination of the wood's density by reflecting the actual volume of the wood in its natural and unshrunk state (13,24).

**2.4. Comparison of Local Wood Density with Global Wood Density Patterns**

The computed wood densities of selected Bhutanese conifers, including *J. recurva, P. spinulosa*, and *A. densa,* were compared with the Global Wood Density Database (25) to assess and report variations. This comparison helps determine whether Bhutanese conifers exhibit distinct density characteristics relative to global averages.

3. results and discussion

Figure 2, 3, and 4 below delineate the regional variations in basic wood density for *Juniperus recurva, Abies densa, and Picea spinulosa* across four physiographic zones: west, west-central, east-central, and eastern. In Figure 2(a), the wood density of *Juniperus recurva* is presented for the west (0.4135 g/cm3), west-central (0.3947 g/cm3), east-central (0.4080 g/cm3), and eastern (0.3797 g/cm3) regions, with an overall average of 0.4094 g/cm3 across all regions. Similarly, the basic wood density of *Abies densa* for the west (0.3785 g/cm3), west-central (0.3125 g/cm3), east-central (0.3107 g/cm3), and eastern (0.3041 g/cm3) regions, yielding an overall average of 0.3211 g/cm3. Additionally, Figure 3. presents the wood density of *Picea spinulosa* for the west (0.3772 g/cm3), west-central (0.3458 g/cm3), and east-central (0.3329 g/cm3) regions, with an overall average of 0.3424 g/cm3 across all regions.

**Figure 2: Summary of wood density according to regions for *Juniperus recurva***

**Figure 3. Summary of wood density according to regions of *Abies densa***

**Figure 4. Summary of wood density according to regions for *Picea spinulosa***

Table 1, 2, and 3 presents the maximum and minimum average wood density data for *Juniperus recurva, Abies densa,* and *Picea spinulosa* based on various parameters like diameter at breast height (DBH) over bark, tree height, disc dry weight, disc diameter, average diameter width, disc volume, and disc density. In Table 1, shows the calculated maximum average density for *Juniperus recurva* is 0.5422 g/cm3, and the minimum average density is 0.3146 g/cm3, with an overall average wood density of 0.4094 g/cm3. Similarly, Table 2 displays the calculated maximum average density for *Abies densa* as 0.8705 g/cm3, and the minimum average density as 0.1928 g/cm3, resulting in an overall average wood density of 0.3211 g/cm3. Likewise, for *Picea spinulosa* in Table 3, the calculated maximum average density is 0.4497 g/cm3, and the minimum average density is 0.2490 g/cm3, with an overall average wood density of 0.3424 g/cm3.

**Table 1. Wood density of *Juniperus recurva***

|  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- |
| Sl No | DBH Over Bark (cm) | Tree Ht. (m) | Disc dryWeight Inner Bark (g) | DiscDiameter\_Inner Bark(cm) | Average Disc width (cm) | Discvolume (cm3) | Discdensity (g/cm3) | Averagedensity(g/cm3) |
| **Max** | 85.00 | 32.40 | 16448.97 | 83.17 | 9.25 | 33465.92 | 1.2323 | **0.5422** |
| **Min** |  6.60 |  1.30 |  1.46 |  1.92 | 3.83 |  14.41 | 0.1138 | **0.3146** |
| **Avg** | 36.64 | 17.46 |  1732.72 | 26.40 | 5.91 |  3868.77 | 0.4077 | **0.4094** |

**Table 2. Wood density of *Abies densa***

|  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- |
| Sl No | DBH Over Bark (cm) | Tree Ht. (m) | Disc dryWeight Inner Bark (g) | DiscDiameter\_Inner Bark(cm) | Average Disc width (cm) | Discvolume (cm3) | Discdensity (g/cm3) | Averagedensity(g/cm3) |
| **Max** | 82.00 | 46.60 | 14474.83 | 75.39 | 10.15 | 42519.9 | 1.1084 | **0.8705** |
| **Min** |  5.00 |  3.49 |  16.73 |  3.76 |  3.95 |  57.47 | 0.1634 | **0.1928** |
| **Avg** | 36.19 | 23.24 |  1804.49 | 29.39 |  5.89 | 5661.28 | 0.3202 | **0.3211** |

**Table 3. Wood density of *Picea spinulosa***

|  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- |
| Sl No | DBH Over Bark (cm) | Tree Ht. (m) | Disc dryWeight Inner Bark (g) | DiscDiameter\_Inner Bark(cm) | Average Disc width (cm) | Discvolume (cm3) | Discdensity (g/cm3) | Averagedensity(g/cm3) |
| **Max** | 87.30 | 48.80 | 15392.15 | 83.40 | 9.10 | 37473.67 | 1.2224 | **0.4497** |
| **Min** |  5.60 |  6.06 |  18.23 |  3.90 | 4.15 |  61.40 | 0.0592 | **0.2490** |
| **Avg** | 36.12 | 24.64 |  1998.27 | 29.28 | 5.78 |  5291.60 | 0.3598 | **0.3424** |

The global wood density database does not explicitly list the wood density of *Juniperus recurva, Abies densa,* and *Picea spinulosa,* however it does contain information for various other species as shown in Table 4 (26). For instance, it reports an average wood density of 0.5041 g/cm3 for 14 different *Juniperus* species, with values spanning from 0.4295 g/cm3 to 0.6280 g/cm3, whereas Bhutan's *Juniperus recurva* registers at 0.4094 g/cm3 ranging from 0.3146 g/cm3 to 0.5422 g/cm3. Similarly, it presents an average wood density of 0.3660 g/cm3 for 22 different *Abies* species, ranging from 0.2890 g/cm3 to 0.4410 g/cm3, while *Abies densa* from Bhutan measures at 0.3211 g/cm3 ranging from 0.1928 g/cm3 to 0.8705 g/cm3. Similarly, data on *Picea spinulosa's* wood density is lacking. However, the database does provide an average wood density of 0.3819 g/cm3 for 41 different *Picea* species, ranging from 0.3078 g/cm3 to 0.4415 g/cm3, whereas Bhutanese *Picea spinulosa* records average density of 0.3424 g/cm3 ranging from 0.2490 g/cm3 to 0.4497 g/cm3.

The average wood density of Bhutan’s *Juniperus recurva, Abies densa*, and *Picea spinulosa* falls below the global average wood density. Discrepancies in wood density among these species within Bhutan and globally could be attributed to variations in sample sizes in terms of height, diameter, aspect, altitude, and tree age. This assertion finds support in similar studies indicating that variations in wood density for Sitka spruce in Great Britain could be linked to differing site conditions, silviculture practices, and tree ages across various locations (27). Similarly, studies have demonstrated significant variations in wood density based on site characteristics and tree height. This phenomenon could also reveal the variability in wood density data for Bhutan's *Juniperus recurva, Abies densa,* and *Picea spinulosa* across different regions, likely influenced by varying temperature and rainfall patterns. Studies indicate that wood density generally increases with higher temperatures and precipitation levels irrespective of the species (28).

**Table 4. Comparison of wood density between Global wood density database and Bhutan**

|  |  |  |
| --- | --- | --- |
| **Species** | Global wood density database | Bhutan Wood density |
|  | Range (g/cm3) | Average (g/cm3) | Range (g/cm3) | Average (g/cm3) |
| *Juniperus species* | 0.4295 - 0.6280 | 0.5041 | 0 | 0 |
| *Juniperus recurva* | 0 | 0 | 0.3146 - 0.5422 | 0.4094 |
| *Abies species* | 0.2890 - 0.4410 | 0.3660 | 0 | 0 |
| *Abies densa* | 0 | 0 | 0.1928 - 0.8705 | 0.3211 |
| *Picea species* | 0.3078 - 0.4415 | 0.3819 | 0 | 0 |
| *Picea spinulosa* | 0 | 0 | 0.2490 - 0.4497 | 0.3424 |

4. Conclusion

This study provides the first comprehensive quantification of the wood density of three ecologically and economically significant conifer species in Bhutan: *Juniperus recurva*, *Picea spinulosa*, and *Abies densa*. The findings reveal significant regional variations in wood density, likely influenced by local environmental factors such as altitude, temperature, and precipitation. Among the three species, *J. recurva* exhibited the highest average wood density (0.4094 g/cm³), followed by *P. spinulosa* (0.3424 g/cm³) and *A. densa* (0.3211 g/cm³). These values, when compared to global datasets, highlight both similarities and deviations from broader coniferous wood density patterns, underscoring the unique growth conditions in Bhutan’s high-altitude forests.

The results of this study contribute to a better understanding of the physical properties of Bhutanese conifers, with implications for sustainable forest management, timber utilization, and ecological research. The established baseline data will aid in optimizing wood processing techniques and informing forestry policies. Additionally, the study provides valuable insights for dendrochronological and climate-growth relationship studies, supporting broader scientific efforts in tree-ring research and climate impact assessments. Further studies incorporating a wider range of environmental variables and mechanical property assessments will enhance our understanding of the functional characteristics of Bhutan’s forest resources.

**Disclaimer (Artificial intelligence)**

Option 1:

Author(s) hereby declare that NO generative AI technologies such as Large Language Models (ChatGPT, COPILOT, etc.) and text-to-image generators have been used during the writing or editing of this manuscript.

Option 2:

Author(s) hereby declare that generative AI technologies such as Large Language Models, etc. have been used during the writing or editing of manuscripts. This explanation will include the name, version, model, and source of the generative AI technology and as well as all input prompts provided to the generative AI technology

Details of the AI usage are given below:

1.

2.

3.

References

1. Silva JPM, Fernandes MR de M, Gonçalves AFA, Lopes IL e, Silva GF da, Cabacinha CD. Estimation of the Basic Wood Density of Native Species Using Mixed Linear Models. Floresta e Ambiente. 2019;26(spe1).

2. Yao J, Zhao Y, Lu J, Liu H, Wu Z, Song X, et al. Research on the Wood Density Measurement in Standing Trees through the Micro Drilling Resistance Method. Forests. 2024 Jan 15;15(1):175.

3. Castillo-Figueroa D, González-Melo A, Posada JM. Wood density is related to aboveground biomass and productivity along a successional gradient in upper Andean tropical forests. Front Plant Sci. 2023 Nov 9;14.

4. Rodriguez HG, Maiti R, Kumari A, Sarkar NC. Variability in Wood Density and Wood Fibre Characterization of Woody Species and Their Possible Utility in Northeastern Mexico. Am J Plant Sci. 2016;07(07):1139–50.

5. Saatchi SS, Harris NL, Brown S, Lefsky M, Mitchard ETA, Salas W, et al. Benchmark map of forest carbon stocks in tropical regions across three continents. Proceedings of the National Academy of Sciences. 2011 Jun 14;108(24):9899–904.

6. Baccini A, Goetz SJ, Walker WS, Laporte NT, Sun M, Sulla-Menashe D, et al. Estimated carbon dioxide emissions from tropical deforestation improved by carbon-density maps. Nat Clim Chang. 2012 Mar 29;2(3):182–5.

7. Vieilledent G, Fischer FJ, Chave J, Guibal D, Langbour P, Gérard J. New formula and conversion factor to compute basic wood density of tree species using a global wood technology database. Am J Bot. 2018 Oct 15;105(10):1653–61.

8. Chave J, Andalo C, Brown S, Cairns MA, Chambers JQ, Eamus D, et al. Tree allometry and improved estimation of carbon stocks and balance in tropical forests. Oecologia. 2005 Aug 22;145(1):87–99.

9. FMID. NATIONAL FOREST INVENTORY VOLUME I: STATE OF FOREST REPORT. Vol. I. Department of Forest and Park Services: Thimphu, Bhutan.; 2023.

10. Donegan E, Sola G, Cheng Z, Birigazzi L, Gamarra JGP, Henry M, et al. GlobAllomeTree’s wood density database . 2014.

11. ASTM. Standard test methods for specific gravity of wood and wood-based materials. In: Annual Book of ASTM Standards American Society for Testing and Materials, ASTM International. West Conshohocken: ASTM International; 2006. p. 2935–2401.

12. Simpson WilliamT. Specific gravity, moisture content, and density relationship for wood. . Gen. Tech. Rep. FPL-GTR-76. Madison, WI.; 1993 Jul.

13. Chave J,. Measuring wood density for tropical forest trees a field manual. 31000 Toulouse, France. : Université Paul Sabatier; 2006.

14. Lakatos F,, Mirtchev S. Manual for visual assessment of forest crown condition [Internet]. 1st ed. Food and Agriculture Organization of the United Nations.; 2014 [cited 2025 Jan 1]. 23 p. Available from: https://openknowledge.fao.org/handle/20.500.14283/i4214e

15. Dhonde S, P. N, Shirin F. Correlation Analysis among Growth, Wood Density, and Seed Traits in Gmelina arborea: A Comprehensive Study. Journal of Agriculture and Ecology Research International. 2024 Nov 26;25(6):140–6.

16. Basuki TM, van Laake PE, Skidmore AK, Hussin YA. Allometric equations for estimating the above-ground biomass in tropical lowland Dipterocarp forests. For Ecol Manage. 2009 Mar;257(8):1684–94.

17. Walker W, A. Baccini, M. Nepstad, N. Horning, D. Knight, E. Braun, et al. Field Guide for Forest Biomass and Carbon Estimation. Version 1.0. Massachusetts, USA.: Woods Hole Research Center, Falmouth ; 2011.

18. UWICER. Laboratory Protocols for Drying of Tree Biomass Sample. Forestry Laboratory, CFRSC, Yusipang, Ugyen Wangchuck Institute for Conservation and Environmental Research, Department of Forests and Park Services. Lamai Goempa, Bumthang, Bhutan.: UWICER Press; 2018.

19. Gregoire TG, Valentine HT, Furnival GM. Sampling Methods to Estimate Foliage and Other Characteristics of Individual Trees. Ecology. 1995 Jun;76(4):1181–94.

20. FRMD. Randomized Branch Sampling Field Protocol for Aboveground Tree Biomass Estimation. . Department of Forests and Park Services. Royal Government of Bhutan. ; 2012.

21. Gregoire TG, Valentine HT. Sampling Strategies for Natural Resources and the Environment. Chapman and Hall/CRC; 2007.

22. Forest Products Laboratory. Wood Handbook - wood as an engineering material. General Technical Report FPL-GTR-282. Madison, WI: U.S. Department of Agriculture, Forest Service, Forest Products Laboratory.; 2021. 543 p.

23. Mayavel A, Esakkiammal S, Chitra P, Nicodemus A, Kamalakannan R. Variation in Growth, Wood Basic Density and Fiber Characters in Selected Clones of Acacia auriculiformis A. Cunn. Ex benth. Int J Plant Soil Sci. 2022 Aug 30;1123–33.

24. Barbosa RI, Fearnside PM. Wood density of trees in open savannas of the Brazilian Amazon. For Ecol Manage. 2004 Sep;199(1):115–23.

25. Chave J, Coomes D, Jansen S, Lewis SL, Swenson NG, Zanne AE. Towards a worldwide wood economics spectrum. Ecol Lett. 2009 Apr 10;12(4):351–66.

26. Zanne AE, Lopez-Gonzalez G, Coomes DA, Ilic J, Jansen S, Lewis SL, et al. Data from: Towards a worldwide wood economics spectrum[Dataset]. 2009.

27. Gardiner B, Leban JM, Auty D, Simpson H. Models for predicting wood density of British-grown Sitka spruce. Forestry. 2013 Apr 1;86(2):295–295.

28. Giroud G, Bégin J, Defo M, Ung CH. Regional variation in wood density and modulus of elasticity of Quebec’s main boreal tree species. For Ecol Manage. 2017 Sep;400:289–99.