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SHORT COMMUNICATION

Wood specific gravity of some tree species in the Garhwal Himalayas, India

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Abstract Estimation of terrestrial biomass depends critically on reliable information about wood specific gravity of forest trees. In recent years, wood specific gravity has become more important when exploring the universality of functional traits of plants and estimating their global carbon stocks. To estimate their specific gravity, wood samples were collected from a total of 34 tree species, 30 from lower elevations and 4 from upper elevations in the Garhwal Himalayas, India. The results show that the average wood specific gravity was 0.631 (ranging between 0.275 ± 0.01 and 0.845 ± 0.03) for the species at lower elevations and 0.727 (ranging between 0.628 ± 0.02 and 0.865 ± 0.02) for the upper elevations. The average wood specific gravity for the upper elevation species was 9.6% greater than that for the species at lower elevations. *Aegle marmelos* among the lower elevation species and *Quercus leucotrichophora* among the upper elevation species had the highest wood specific gravity, which were 0.845 ± 0.03 and 0.865 ± 0.02, respectively.

Key words specific gravity, biomass, elevation

1 Introduction

Wood specific gravity is the single best descriptor of functional properties of wood and life-history traits of trees and the most important variable in estimating above- and below-ground biomass and carbon stocks in forests. Above-ground biomass estimation is essential for the study of carbon stocks and the effects of deforestation and carbon sequestration on the global carbon balance (Ketterings et al., 2001). Estimation of above-ground biomass is also useful to measure and compare structural and functional properties of forest ecosystems across different environmental conditions (Brown et al., 1999). Wood specific gravity plays an important role in converting forest volume to biomass (Fearnside, 1997), although it may strongly depend on other factors such as climate, location and management practices (Ketterings et al., 2001). It is highly correlated with carbon density per unit volume and in turn, is of direct applied importance in estimating ecosystem carbon storage and fluxes (Brown, 1997; Fearnside, 1997; Nelson et al., 1999; Baker et al., 2004a; Muller-Landau, 2004; Mani and Parthasarathy, 2007).

Wood specific gravity is a direct reflection of the amount of carbon present in the forest, since biomass consists of about half carbon by dry weight (Woodcock and Shier, 2003). To make accurate estimation of the carbon stocks in the forests, there is a growing need for accurate estimation of tree biomass on large spatial scales (Cummings et al., 2002; Chave et al., 2004; Nascimento and Laurance, 2004). For biomass estimation, wood specific gravity is an important component (Baker et al., 2004b; Magcale-Macandog, 2004; Nogueira et al., 2005; Silk, 2006). In the estimation of carbon stocks in tropical forests, the major source of error is the selection of allometric models for converting structural tree data into above-ground biomass (Araújo et al., 1999; Chave et al., 2004, 2005). However, stand-level wood specific gravity still explains 29.7% and 45.4% of the total variation in the above-ground biomass in Amazonian forests, when using different allometric equations (Baker et al., 2004b; Silk, 2006).

There is increasing interest in estimating the biomass of forests and their role in regulating the cycling of carbon and nutrients. So far, no studies have been carried out on the estimation of wood specific gravity in the forests of the central Himalayas, India. Therefore, the main objective of the present study was to

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estimate the wood specific gravity of several dominant tree species from the Garhwal Himalayas.

2 Materials and methods

2.1 Location and climate

The Garhwal Himalayas are located between 29°31′09″–31°26′05″N and 70°35′05″–80°06′05″E, which exhibit a sub-montane to alpine climate, with distinct characteristics of specific types of vegetation. The study area was divided by two different elevations, i.e., lower and upper elevations (Fig. 1). The lower level (30°29′N, 78°24′E) was located in the Tehri Garhwal District between 580 to 900 m elevation above mean sea level (a.m.s.l.). The mean annual temperature in this region varies between 10 and 23°C and the mean January temperature between 10 and 15°C. The total annual precipitation is 960 mm. The upper level (30°23′N, 78°20′E) was located 40 km north-east of Srinagar City of Garhwal Himalayas between 1900–2300 m a.m.s.l. The mean annual temperature in this region ranges between 7 and 15°C and the mean January temperature between –1 and 7°C. The total annual precipitation is about 1600 mm. The area is characterized by a pronounced winter season with much frost and snow.

2.2 Methods

The present study involved a collection of wood samples from 34 tree species in the study area. At the lower elevations wood samples were collected randomly from 30 tree species and at the upper elevations wood samples were collected from only four available tree species. The trees were cored at breast height of 1.37 m to determine their wood specific gravity. Wood specific gravity within individual trees often varies vertically along the main axis of the stem and/or radically from the pith to the bark. To avoid the error of ignoring this variation, the entire stem core from pith to bark was collected for the determination of specific gravity. For each tree species, three samples were taken from mature trees of different girth classes and the mean of the three samples was considered as the specific gravity of that species. Wood samples were collected in April–June 2010. The collected wood samples were weighted for fresh weight and then dried in an oven at 105 ± 2°C for 48 h. The specific gravity was calculated using the maximum moisture content method (Smith, 1954). This technique for obtaining specific gravity on the basis of green volume is simple

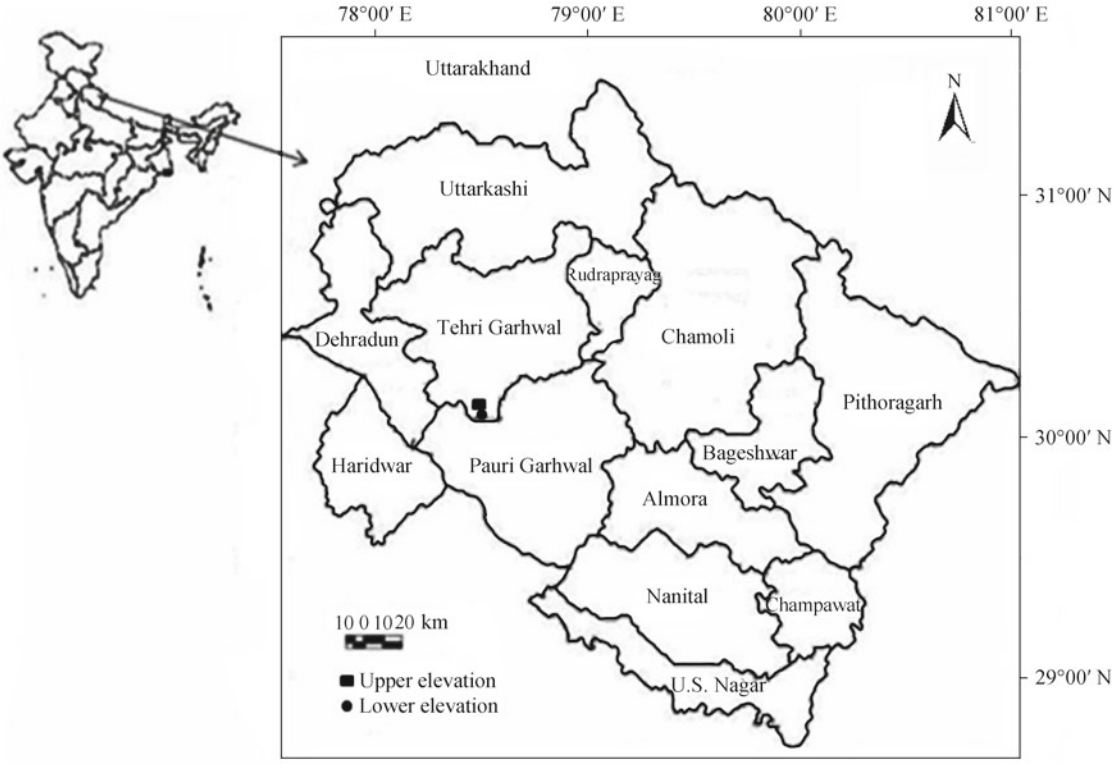

Fig. 1 Location map of the study area

and requires only determining the weight of water-saturated samples and the weight of the oven-dried samples, both of which may be measured with almost same precision.

$$G_{\mathrm{f}} = \frac{1}{\dfrac{M_{\mathrm{m}} - M_{\mathrm{o}}}{M_{\mathrm{o}}} + \dfrac{1}{G_{\mathrm{so}}}} \tag*{1)}$$

where G_{f} is the wood specific gravity based on gross volume, M_{m} the weight of water-saturated samples, M_{o} the weight of oven-dried samples and G_{so} the density of wood. For G_{so}, a constant value of 1.53 is usually adopted.

3 Results and discussion

The specific gravity of wood was determined for a total of 34 tree species, 30 from the lower elevations and four from the upper elevations. Figure 2 demonstrates the relationship between wood specific gravity and the number of tree species. As shown in Fig. 2, the specific gravity of the maximum number of species (11) is found between 0.60–0.70, followed by 0.70–0.80 (10) and only one species has a specific gravity less than 0.30.

The average wood specific gravity was 0.631 (ranging from 0.275 ± 0.01 to 0.845 ± 0.03) for the lower elevation species and 0.727 (ranging from 0.628 ± 0.02 to 0.865 ± 0.02) for the upper elevations (Table 1). Among the species at the lower elevations, *Aegle marmelos* had the highest specific gravity and among the four species at the upper level *Quercus leucotrichophora* had highest. *Moringa oleifera*, *Jatropha curcas* and *Ficus auriculata* at the lower elevations had low specific gravity, as had *Rhododendron arboreum* and *Lyonia ovalifolia* at the upper elevations. The highest specific gravity among all species was found in *Quercus leucotrichophora*, which was slightly higher than the values reported by Rajput et al. (1985). Among the lower level species, the highest specific gravity (0.845), in *Aegle marmelos*, is between 0.78 –0.94 as reported by Ghosh et al. (1963), but slightly higher than the values reported by Rajput et al. (1985) in Gonda (UP) and Chowdhury and Ghosh (1958; 0.754). In the present study, the specific gravity of *Cassia fistula* (0.812), *Anogeissus latifolia* (0.795), *Mangifera indica* (0.750), *Morus alba* (0.746), *Grewia optiva* (0.714), *Lagerstroemia parviflora* (0.713), *Quercus leucotrichophora* (0.865) and *Rhododendron arboreum* (0.628) were higher than the reported values of Indian timber (*Cassia fistula*, 0.746; *Anogeissus latifolia*, 0.757; *Mangifera indica*, 0.588; *Morus alba*, 0.603; *Grewia optiva*, 0.606; *Lagerstroemia parviflora*, 0.620; *Quercus leucotrichophora*, 0.826; *Rhododendron arboreum*, 0.512). Specific gravity of *Acacia catechu* (0.776), *Olea glandulifera* (0.754), *Dalbergia sissoo* (0.683) and *Ougeinia oojeinensis* (0.606) was lower than that reported for *Acacia catechu* (0.825), *Olea glandulifera* (0.781), *Dalbergia sissoo* (0.692) and *Ougeinia oojeinensis* (0.704) (Chowdhury and Ghosh, 1958; Purkayastha, 1982; Raturi et al., 2002). These variations might be due to changes in soil fertility, rainfall, seasonality and temperature, because the wood samples used by these authors were mostly collected from the sub-tropical and tropical plain areas, whereas in the present study the wood samples were collected from hilly terrains. The variation in average specific gravity due to these factors has also been reported by Muller-Landau (2004).

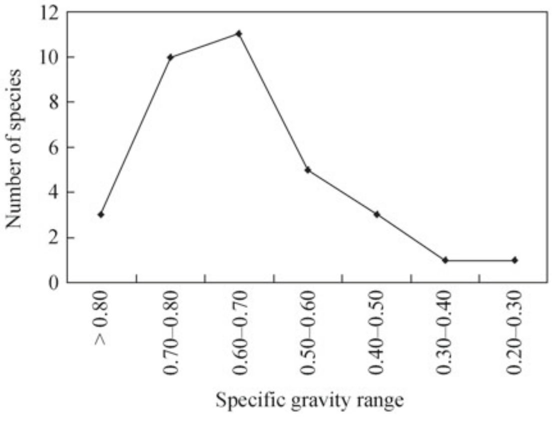

Fig. 2 Specific gravity vs. number of species in different range classes

The average wood specific gravity of species at the upper elevations was greater (9.6%) than that at lower levels. The variation in wood specific gravity of species within and across the lower and upper elevations may be due to variation in mean annual precipitation. Working in the same area, Kumar et al. (2009) showed 960 mm precipitation in the forests at the lower elevations and 1600 mm at the upper elevations. A positive correlation of specific gravity with precipitation was also reported by Mani and Parthasarathy (2007), who revealed higher mean specific gravity at coastal sites where precipitation was 33.4% greater than that at inland sites. The difference in mean specific gravity in species between lower and upper levels may also be due to increasing elevation. The trend of increasing specific gravity from 0.521 (1050 m a.s.l.) to 0.535 (1400 m a.s.l.) and 0.606 (1800 m a.s.l.) has been reported by Culmsee et al. (2010). In addition, the highest specific gravity was found in the Fagaceae family which may be the reason for maximum mean specific gravity at higher elevations. In the tropical montane rain forests of Indonesia, the highest specific gravity, with an average of 0.672, was also found in Fagaceae species (Culmsee et al., 2010). Variations in wood

Table 1 Average (± SD) wood specific gravity of tree species in the Garhwal Himalayas

Species	Family	Status	Specific gravity	Reported value
Lower elevation				
Aegle marmelos (L.) Correa	Rutaceae	Deciduous	0.845 ± 0.03	0.754*
Cassia fistula L.	Caesalpiniaceae	Deciduous	0.812 ± 0.00	0.746**
Anogeissus latifolia (Roxb. ex DC.) Wall. ex Guill. & Perr.	Combretaceae	Deciduous	0.795 ± 0.07	0.757**
Acacia catechu (L.f.) Willd.	Mimosaceae	Deciduous	0.776 ± 0.04	0.825**
Olea glandulifera Wallich ex G. Don	Oleaceae	Deciduous	0.754 ± 0.03	0.781**
Mangifera indica L.	Anacardiaceae	Evergreen	0.750 ± 0.00	0.588*
Leucaena leucocephala (Lam.) de Wit.	Mimosaceae	Deciduous	0.747 ± 0.01	0.601****
Morus alba L.	Moraceae	Deciduous	0.746 ± 0.15	0.603**
Celtis australis L.	Ulmaceae	Deciduous	0.716 ± 0.05	0.444****
Grewia optiva J.R. Drummond ex Burret	Tiliaceae	Deciduous	0.714 ± 0.01	0.606**
Lagerstroemia parviflora Roxb.	Lythraceae	Deciduous	0.713 ± 0.02	0.620*
Melia azedarach L.	Meliaceae	Deciduous	0.691 ± 0.01	0.491***
Dalbergia sissoo Roxb.	Fabaceae	Deciduous	0.683 ± 0.02	0.692***
Syzygium cumini (L.) Skeels	Myrtaceae	Deciduous	0.669 ± 0.02	0.647***
Mallotus philippensis (Lam.) Muell.-Arg.	Euphorbiaceae	Evergreen	0.649 ± 0.01	0.571***
Pinus roxburghii Sargent	Pinaceae	Evergreen	0.632 ± 0.08	0.491****
Emblica officinalis Gaertn.	Euphorbiaceae	Deciduous	0.614 ± 0.03	–
Ougeinia oojeinensis (Roxb.) Hochr.	Fabaceae	Deciduous	0.606 ± 0.03	0.704**
Cordia myxa auct. Pl.	Ehretiaceae	Deciduous	0.601 ± 0.06	0.441**
Holoptelea integrifolia (Roxb.) Planch.	Ulmaceae	Deciduous	0.600 ± 0.03	0.498****
Bauhinia retusa Buch.-Ham. ex Roxb.	Caesalpiniaceae	Deciduous	0.594 ± 0.03	–
Adina cordifolia (Roxb.) Hook. f. ex Brandis	Rubiaceae	Deciduous	0.590 ± 0.02	0.583**
Ficus palmata Forsk.	Moraceae	Deciduous	0.578 ± 0.01	–
Toona ciliata Roemer	Meliaceae	Deciduous	0.554 ± 0.03	0.424****
Madhuca longifolia (Koenig) MacBride	Sapotaceae	Deciduous	0.504 ± 0.01	0.728
Ficus elastica Roxb.	Moraceae	Deciduous	0.497 ± 0.06	–
Lannea coromandelica (Hout.) Merrill	Anacardiaceae	Deciduous	0.467 ± 0.03	0.497**
Ficus auriculata Lour.	Moraceae	Deciduous	0.443 ± 0.01	–
Jatropha curcas L.	Euphorbiaceae	Deciduous	0.314 ± 0.01	–
Moringa oleifera Lam.	Moringaceae	Deciduous	0.275 ± 0.01	0.299****
Upper elevation				
Quercus leucotrichophora A. Camus	Fagaceae	Evergreen	0.865 ± 0.02	0.826***
Myrica esculenta Buch.-Ham. ex D. Don	Myricaceae	Evergreen	0.737 ± 0.03	–
Lyonia ovalifolia (Wall.) Drude	Ericaceae	Deciduous	0.677 ± 0.28	–
Rhododendron arboreum Smith	Ericaceae	Deciduous	0.628 ± 0.02	0.512***

Note: * means Chowdhury and Ghosh (1958); ** Purkayastha (1982); *** Raturi et al. (2002) and **** Rajput et al. (1985).

quality with tree growth are strongly related to physical and chemical properties of the soil (Rigatto, 2004). Other variations in wood are the result of environmental factors such as temperature, light, water and internally controlled genetic factors (Larson, 1969; Zobel and Jett, 1995).

In the last few years, wood specific gravity has become a popular topic as plant biologists search for broad-spectrum functional traits and to determine their ecological and evolutionary significance (Muller-Landau, 2004; King et al., 2006; van Gelder et al., 2006; Swenson and Enquist, 2008; Chave et al., 2009). Specific gravity has been acclaimed as the integrator of wood properties in the “wood economics spectrum” given its importance in structure, storage and translocation (Chave et al., 2009). In addition, specific gravity is the primary variable in the estimation of biomass to assess global carbon stocks (Brown and Lugo, 1992; Fearnside, 1997; Chave et al., 2005; Nogueira et al., 2005; Malhi et al., 2006; Keeling and Phillips, 2007; Baker et al., 2009). The above-ground biomass in Amazonian lowland rain forests has been found to be determined largely by wood specific gravity (Baker et al., 2004b; Malhi et al., 2006), a trait highly dependent on phylogeny (Baker et al., 2004b; Slik, 2006). Therefore, if more general patterns are to be recognized, analyses of changes in above-ground biomass as a function of elevation must consider profound changes in forest community composition and their related traits, in addition to changes in forest structure.

4 Conclusions

Specific gravity reflects the amount of wood substance or biomass deposited per unit volume of a living tree trunk and is thus a factor affecting the amount of forest biomass (Wiemann & Williamson, 1988). So far no studies have been carried out in this region on the estimation of specific gravity of trees. This study will help researchers who are working on biomass and carbon estimation and will make it possible to produce more accurate estimates of the above-ground carbon stocks present in these forests. Data on the wood specific gravity of tree organs, in particular stem wood, are essential for accurate assessments of forest carbon sequestration.

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