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Forest inventory and analysis in Gilgit-Baltistan

A contribution towards developing a forest inventory for all Pakistan

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Abstract

Purpose – The purpose of the study is to analyse the occurrence and distribution of different tree species in Gilgit-Baltistan, Pakistan, as a baseline for further inventories, and estimate the biomass per species and plot. Furthermore, it aims to measure forest biodiversity using established formulae for tree species diversity index, richness, evenness and accumulative curve.

Design/methodology/approach – Field data were collected, including stratification of forest sample plots. Statistical analysis of the data was carried out, and locally appropriate allometric equations were applied for biomass estimation.

Findings – Representative circular 556 forest sample plots of 1,000 m^2 contained 13,135 trees belonging to nine tree species with a total aboveground biomass of 12,887 tonnes. Sixty-eight per cent of the trees were found between 2,600 and 3,400 masl; approximately 63 per cent had a diameter at breast height equal to 30 cm, and 45 per cent were less than 12 m in height. The Shannon diversity index was 1.82, and Simpson's index of diversity was 0.813.

Research limitations/implications – Rough terrain, long distances, harsh weather conditions and location of forest in steep narrow valleys presented challenges for the field crews, and meant that fieldwork took longer than planned.

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Practical implications – Estimating biomass in Gilgit-Baltistan's forests using locally developed allometric equations will provide transparency in estimates of forest reference levels, National Forest Monitoring System in Pakistan and devising Reducing Emissions from Deforestation and Forest Degradation national strategies and for effective implementation.

Originality/value – This paper presents the first detailed forest inventory carried out for the dry temperate and semi-arid cold region of Gilgit-Baltistan, Pakistan.

Keywords REDD+, Forest inventory, Forest monitoring, Gilgit-Baltistan

Paper type Research paper

1. Introduction

Forest ecosystems contribute substantially to securing water supplies, providing economic goods, maintaining biodiversity and mitigating climate change, as well as provide many of the world's poorest people with income, food and medicine (Shahzad *et al.*, 2015). Pakistan's forests are heterogeneous, reflecting the great physiographic and climatic contrasts within the country that result from the latitudinal spread and immense variations in altitude (Champion *et al.*, 1965). Pakistan spans a number of the world's ecological regions and the forests range from the coastal mangrove forests of the Arabian Sea to the high mountain forests of the western Himalayas, Hindu Kush and Karakoram ranges (Champion *et al.*, 1965). In Pakistan, predominantly coniferous alpine, sub-alpine and temperate forests in the north and northwest mountains and hills exist (FAO, 2007).

Overall, forest cover in Pakistan is very low, estimated at 2.5 per cent of the total area. This is partly due to the arid and semi-arid climate in many parts, but it is also the result of overdependence of local populations on the forests, leading to high rates of deforestation (FAO, 2007). A recent study by Qamer *et al.* (2016) using time-series decadal forest cover change maps (1990, 2000 and 2010) showed extensive deforestation and degradation in northern Pakistan (Gilgit-Baltistan and Khyber Pakhtunkhwa), with 1,707 km^2 of forest area lost over 20 years, 8 per cent of the total or 0.38 per cent per year. Although efforts have been put in place to devise strategies and polices to conserve the country's remaining forests in the north, particularly in Gilgit-Baltistan, these forests continue to be managed in an unsustainable manner and deforestation and degradation remain major concerns (Ali *et al.*, 2006; Hasan, 2007; Yusuf, 2009). Fuelwood demand is very high, especially in winter, as a result of the cold and lack of alternative energy sources. Most timber and fuelwood harvesting is carried out unofficially (often by what is locally known as the "timber mafia"; Ali and Benjaminsen, 2004). Extensive logging has dramatically reduced the remaining forest cover of pine, spruce, deodar cedar and juniper, and had an enormous negative effect on both wildlife and livelihoods. Mining activity conducted in forest areas has also led to heavy losses and increased deforestation and forest degradation. Forest loss puts soils at risk of erosion from even minor rain events, and this is especially true for soils found on steep slopes as are found throughout Diamer District's precipitous mountainous terrain (Akbar *et al.*, 2014).

Although limited in extent, Pakistan's forests play a significant economic and environmental role. They make a significant contribution to the livelihood security of the millions of rural people who live in areas close by (Shahbaz *et al.*, 2007) and provide a wide range of environmental services, including water and soil conservation, regulation of water yield, protection from landslides, carbon sequestration, amelioration of climate, conservation of biodiversity and ecotourism. These services have received little attention or appreciation in Pakistan until recently (Shahbaz *et al.*, 2007; Siddiqui *et al.*, 1999), when the environmental functions of forests have been highlighted by emerging concepts like REDD+ (Reducing

Emissions from Deforestation and Forest Degradation). This change in awareness is now shaping the strategies and priorities of both national government and provincial authorities, especially since the 18th amendment to the Constitution of Pakistan (decision powers distributed to provinces; Adeney, 2012).

Studies of forest cover are limited. In the 1990s, the Government of Pakistan prepared a 25-year (1993-2018) Master Plan for Forestry Development, which was based on a forest assessment at the national level prepared using satellite imagery and fieldwork. The assessment was conducted in 1990/1991 using 54 Landsat satellite images at a scale of 1:250,000 covering the whole area of Pakistan. The image quality was acceptable, except in the mountainous northern regions, where sparse coniferous forest was not distinguishable from scrub forest, leaving about 47,000 of 70,400 km^2 in the northern areas unclassified (FAO, 2007). The most recent study at the national level is the Land Cover Atlas 2011 conducted by the Pakistan Forest Institute, who reported a total forest cover, excluding alpine pastures, farmland trees and plantations, of 5.1 per cent (Ali, 2013).

Studies of forest biomass in Pakistan are also limited (Nizami, 2014). The FAO Global Forest Resources Assessment reports for 2005 and 2010 included baseline carbon stock estimates prepared at coarse spatial resolution (Kindermann *et al.*, 2008), while a number of authors have estimated the biomass of specific tree species. Nizami *et al.* (2009) estimated the biomass of sub-tropical *Pinus roxburghii* (chir pine) forest in Murree Forest Division, Punjab, using allometric equations developed for the Indian Himalayan ecosystem, whereas Abbas *et al.* (2011) estimated the biomass of *Olea ferruginea* (Indian olive) in Lehtrar, Murree Forest Division, for whole trees and individual components. Gulzar *et al.* (2014) estimated the biomass of *Dalbergia sissoo* (shisham) in irrigated plantation areas in Mandi Bahuddin, Punjab, using allometric equations developed using destructive sampling, and Ahmad *et al.* (2014) estimated the biomass of coniferous forest in Swat and Kohistan using inventory data and allometric relationships developed for Indian forests.

Pakistan is a signatory to the United Nations Framework Convention on Climate Change (UNFCCC) and has a clear vision for keeping pace with the global community to mitigate the adverse impacts of climate change. Reducing emissions from the forestry sector has been recognized as playing a pivotal role in mitigating and adapting to climate change, and Pakistan's plans include participating in the REDD+ mechanism, an international climate policy instrument that links economic incentives with the conservation and management of forest resources (Beaudoin *et al.*, 2016). However, the lack of data on forest cover and biomass is a substantial hindrance in view of the discussions on forest monitoring for REDD+ implementation and the need to develop efficient forest management policies (Qamer *et al.*, 2016).

Pakistan has already entered the REDD+ readiness phase and has joined various international programmes to strengthen its institutional infrastructure and enhance its capacities for REDD+ implementation at the national scale (Hussain and Fatima, 2015; Iqbal and Ahmad, 2011; Roy *et al.*, 2015). The UNFCCC requires REDD+ countries to establish a baseline or national forest reference level, or as an interim measure a subnational forest reference level (FRL), as a benchmark for assessing the country's performance in implementing REDD+ activities. Thus, a comprehensive forest inventory is needed, especially for the northern region, with reliable scientific information that can be used as a reference for REDD+ related activities at both the subnational and the national level. The Ministry of Climate Change recently drafted an Action Plan for implementation of the National Forest Monitoring System (NFMS) in Pakistan (GoP, 2015), which provides a basis for developing such an inventory. The inventory will ultimately contribute to the NFMS in the context of REDD+ planning and implementation.

Specifically, the study aimed:

- to analyse the occurrence and distribution of different tree species in Gilgit-Baltistan as a baseline for further inventories, and estimate the biomass per species and plot; and
- to measure forest biodiversity in Gilgit-Baltistan using established formulae for tree species diversity index, richness, evenness and accumulative curve.

2. Materials and methods

The study involved:

- collection of field data, including stratification of sample plots;
- statistical analysis of the data; and
- applying locally appropriate allometric equations for biomass estimation.

2.1 Study area

Gilgit-Baltistan (formerly Northern Areas) is an administrative unit (divided into ten districts) in the extreme north of Pakistan (Figure 1). It covers an area of 72,971 km^2 (Kazim *et al.*, 2015), including 1,582 km^2 of forest (Qamer *et al.*, 2016), within the high mountain ranges of the Karakorum, Himalayas, Hindu Kush and Pamir. Most of the land lies at or above 4,500 masl. The climatic conditions vary widely, ranging from monsoon-influenced moist temperate in the western Himalayas, to arid and semi-arid cold desert in the northern Karakoram and Hindu Kush. Below 3,000 masl, precipitation is low, rarely exceeding

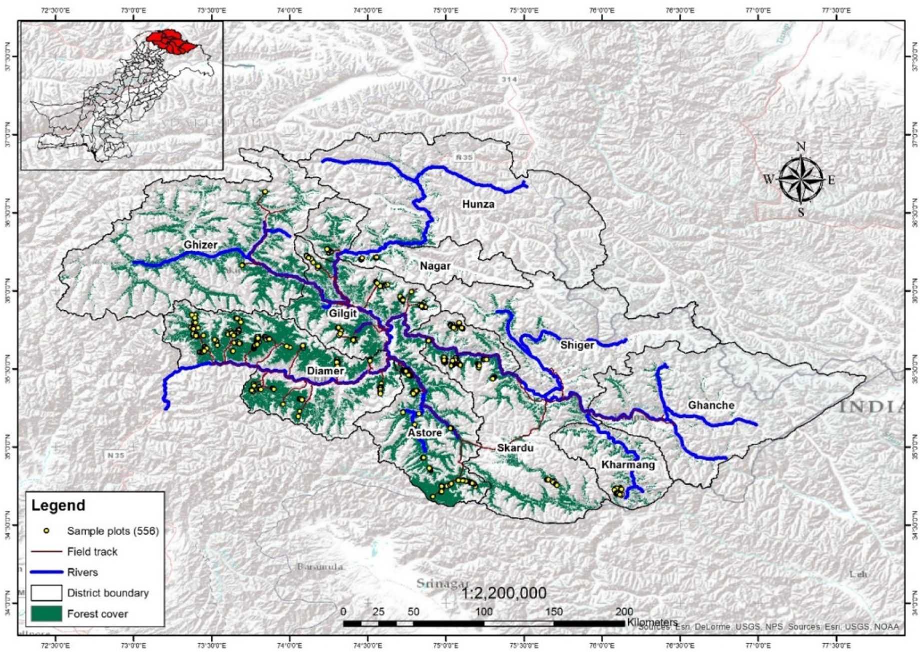

Figure 1.
Study area map shows the distribution of sample plots in Gilgit-Baltistan forested area

200 mm annually, but there is a strong gradient with elevation, and at 6,000 masl, the equivalent of 2,000 mm per year falls as snow. Temperatures in the valley bottoms can range from extremes of 40°C in summer to −10°C in winter (Akbar *et al.*, 2011; Kazim *et al.*, 2015).

2.2 Sample design and field campaign

The forest in Gilgit-Baltistan is very fragmented and exists mostly in patches in the valleys (Qamer *et al.*, 2016). Stratified random sampling [equation (1)] was used to determine the optimum number of sample plots in the selected study areas based on the forest area reported by Qamer *et al.* (2016):

$$n = \frac{t^2 \sum_{j=1}^{M} PjSj^2}{E^2} \tag{1}$$

where:

- n = minimum number of samples required;
- t = *t-values* associated with specified probability;
- M = number of strata in population;
- Pj = proportion of total forest area in the jth stratum = Nj/N;
- Nj = total area of sampling units in the jth stratum;
- N = total area of sampling units in the population;
- Sj^2 = variance of X for the jth stratum; and
- E = allowable standard error in units of X (Husch *et al.*, 2003).

The location and extent of different forest classes (dense and sparse coniferous, broadleaved and mixed forest) and their total area were taken from a previous study (Qamer *et al.*, 2016). The number of sample plots within each stratum was calculated using equation (1), and the plots then allocated randomly within these areas. A total of 556 sample plots of 1,000 m^2 (0.04 per cent of the total forest area) were selected for measurement in the field (Figure 1).

Field campaigns were conducted in June to October 2015 and 2016. Circular plots with a radius of 17.84 m (area 1,000 m^2, i.e. 0.1 ha) were laid out in the forest area using the geographic coordinates determined by the random sampling. A slope correction factor was calculated for each plot based on the slope percentage (per cent) and used to determine the actual plot radius. The following tree parameters were recorded in each plot: DBH (diameter at breast height, only when ≥5 cm), height (only ≥2 m), crown diameter and species. The location was identified using a global positioning system receiver, tree height was measured with a vertex IV hypsometer, DBH was measured using a diameter tape and forest photographs were recorded using a digital camera.

2.3 Occurrence and distribution of tree species

The first part of the analysis focused on the percentage occurrence of different tree species, distribution of trees in different DBH intervals, presence of tree species in different elevation bands, distribution and percentage of trees with different tree heights and DBH class versus elevation range.

The total basal area (BA), relative frequency (RF), relative density (RD), relative abundance (RA), relative coverage and importance value index (IVI) of the nine tree species identified were calculated using the formulae developed by Zobel *et al.* (1987).

2.4 Tree allometric equations and biomass estimation

Much of the uncertainty in the amount and spatial variation of aboveground biomass (AGB) in Pakistan results from the lack of allometric equations for local tree species. The Gilgit-Baltistan Forest Department has recently taken the initiative to calculate tree allometric equations for six of the key species in the forests of Gilgit-Baltistan (*Cedrus deodara, Pinus wallichiana, Pinus gerardiana, Abies pindrow, Picea smithiana* and *Quercus ilex*). The equations were developed using destructive sampling as described in the paper by Ali (2015).

Biomass calculations were carried out for the nine species identified in the plots, six using the allometric equations developed by the Gilgit-Baltistan Forest Department, and three (*Betula utilis, Juniperous communis* and *Taxus baccata*) using allometric equations from other sources (Table I). All the equations except those for *Betula utilis* calculate dry biomass, which was converted into living AGB using a multiplication factor of 2.

Total tree AGB was calculated for each sample plot in tonnes by summing the AGB of individual trees. The biomass was also calculated for individual tree species (total, average, standard deviation and variance) and forest strata.

2.5 Tree species diversity index, richness, evenness, and accumulation curve

The Shannon diversity index [H', equation (2)] was used to measure species diversity. It is characterized by the number of individuals observed for each species in the ecosystem and is often used when studying a random sample from a larger community. Higher values indicate more equal abundance of the different species, and lower values indicate less equal abundance of the different species:

$$H' = \sum_{i=1}^{s} -(Pi \times lnPi) \tag{2}$$

where:

H' = the Shannon diversity index;

Pi = fraction of the entire population made up of species i; and

s = number of species encountered. (Note: ln is the natural logarithm, i.e. the power to which base e [e = 2.718281828] must be raised to obtain the number.)

Species	Equation	Parameters	Reference
Abies pindrow	$0.0954 \times (D^2H)^{0.8114}$		Ali (2015)
Cedrus Deodara	$0.1779 \times (D^2H)^{0.8103}$		Gilgit-Baltistan, Forest Department
Picea smithiana	$0.0843 \times (D^2H)^{0.8472}$		
Pinus wallichiana	$0.0631 \times (D^2H)^{0.8798}$		
Pinus gerardiana	$0.0253 \times (D^{2.6077})$		
Quercus ilex	$0.8277 \times (D^2H)^{0.06655}$		
Taxus baccata	$\text{Exp}(\beta 0 + \beta 1 \ln D)$	$\beta 0 = -0.7152$	Jenkins *et al.* (2003)
Juniperous spp.		$\beta 1 = 1.7029$	
Betula utilis	$(-0.280741) + 3.515265 \times (D)$		GoI (1979)

Notes: D = diameter at breast height (DBH), H = tree height

Table I. Tree species allometric equations for biomass estimation – Gilgit-Baltistan, Pakistan

Species richness was calculated as the total number of species recorded. Species evenness was calculated using the index J' proposed by Pielou (1975) [equation (3)], which indicates how evenly the species are distributed in a designated community:

$$J' = H'/H'max \tag{3}$$

where:

H' = the Shannon diversity index; and

H'_{max} = maximum value of H' (maximum possible diversity) in the community if all the tree species are equally frequent.

Diversity was further characterized using Simpson's index (D) [equation (4)], Simpson's index of diversity (1-D) and Simpson's reciprocal index (1/D):

$$D = \sum (n/N)^2 \tag{4}$$

where:

n = total number of trees of particular species; and

N = total number of trees of all species.

The value of D ranges between 0 and 1, where 0 represents infinite diversity and 1 no diversity, i.e. higher values mean lower diversity. To support intuitive understanding, it is more common to use Simpson's index of diversity, or 1-D. This also ranges between 1 and 0, but higher values mean higher diversity – the index represents the probability that two individuals randomly selected from a sample will belong to different species.

Tree species accumulation curves (SACs) were used to compare the diversity properties of different data sets. The curve was calculated using the random method, which calculates the mean SAC and its standard deviation from random permutations of the data, or subsampling without replacement (Gotelli and Colwell, 2001).

3. Results

3.1 Tree distribution

A total of 13,135 trees (DBH ≥5 cm, height ≥2 m) belonging to nine tree species were recorded in the 556 sample plots. Figure 2 shows the number of trees in each of the species as a proportion of total trees. *Pinus wallichiana* and *Picea smithiana* were the most common species, forming 30 per cent and 20 per cent of the total, respectively. *Juniperous communis* and *Pinus gerardiana* were relatively uncommon, comprising around 2 per cent or less of all trees each, and *Taxus baccata* comprised only 0.1 per cent of the total (17 trees).

Approximately 63 per cent of all trees had a DBH ≤30 cm and 37 per cent a DBH of >30 cm. Figure 3 shows the distribution of trees in different height classes; close to half (45 per cent) were less than 12 m in height, and only 6 per cent were more than 32 m in height.

Figure 4 shows the percentage of all trees found in the different elevation ranges, separated into those with DBH greater and those with DBH less than 30 cm. More than two-thirds of all trees (68 per cent) were found between 2,600 and 3,400 masl, with 40 per cent above 3,000 masl.

Figure 5 shows the percentage of trees of different species found in different elevation ranges. More than 90 per cent of *Quercus ilex* is found below 2,600 masl; the majority of *Pinus gerardiana* and *Cedrus deodara* between 2,200 and 3,000 masl; the majority of *Abies*

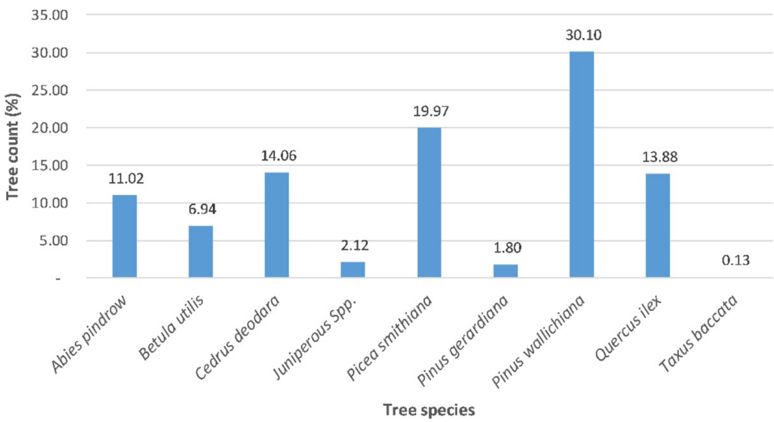

Figure 2.
Species-wise percentage distribution of tree counts

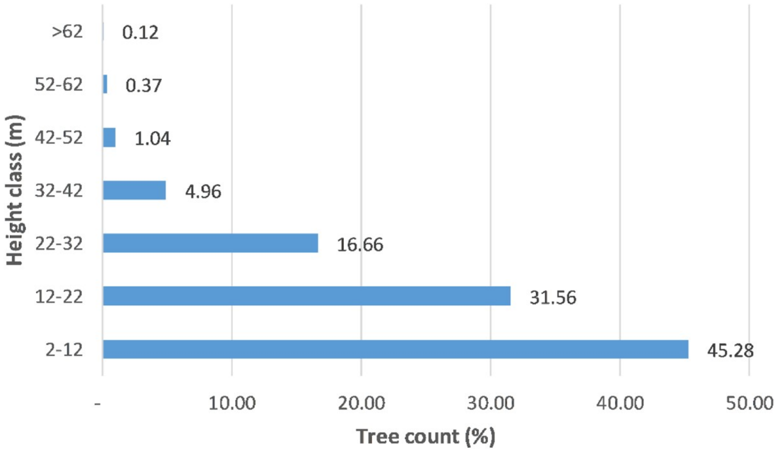

Figure 3.
Tree height-wise percentage distribution of tree counts

pindrow, *Pinus wallichiana*, and *Picea smithiana* between 2,600 and 3,400 masl; and the majority of *Betula utilis* above 3,000 masl. *Juniperous spp*. were observed at all elevations above 2,200 masl, whereas *Taxus baccata* trees were only found in one plot between 2,600 and 3,000 masl.

3.2 Aboveground tree biomass

The total AGB (tonnes) calculated for the individual tree species in the sample plots is shown in Table II, together with the standard deviation (SD), average, maximum, minimum, 95 per cent confidence interval (CI) and standard error (SE). The 556 sample plots with 13,135 trees contained a total tree AGB of 12,887 tonnes. *Pinus wallichiana* contributed the most (3,867 tonnes), closely followed by *Picea smithiana* (3,666 tonnes), and *Taxus baccata* the least (7.3 tonnes).

Table III shows the species values for BA, RF, RD, RA and IVI. Again, *Pinus wallichiana* had the highest values for all these factors, closely followed by *Picea smithiana*, and *Taxus baccata* had the lowest values.

3.3 Tree species diversity index, richness, evenness and accumulation curve

The Shannon diversity index (*H'*) was 1.82 (Table IV); the species evenness was 0.83, Simpson's index (*D*) was 0.187, Simpson's index of diversity was 0.813 and Simpson's reciprocal index was 5.34.

Figure 6 shows the tree SAC, which is an indication of the thoroughness of the survey in terms of the proportion of plant species surveyed. The curve reached a plateau at around 60 samples, which means that after this it is unlikely that additional species would be found. This indicates that sufficient area was sampled to provide a reliable picture of the variation in plant species richness and diversity in the Gilgit-Baltistan forest.

4. Discussion

Forest inventory means the collection of data on trees and their related characteristics in a well-defined area. There have been a number of studies of forest in the dry temperate and semi-arid cold region Gilgit-Baltistan, but they have generally been limited to small areas and a small number of sample plots (Ahmed *et al.*, 2009; Akbar *et al.*, 2011; Akbar *et al.*, 2014; Hasil Khan

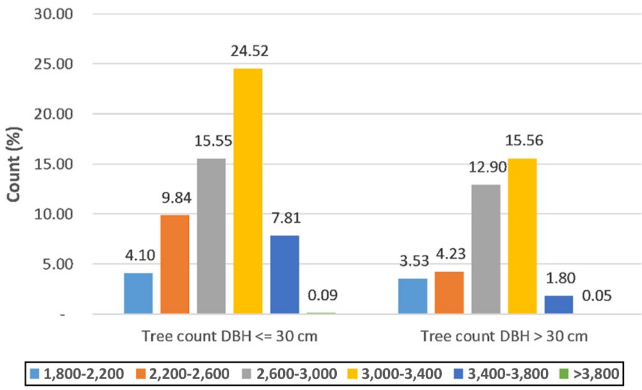

Figure 4.
Elevation interval-wise percentage distribution of tree counts according to DBH classes

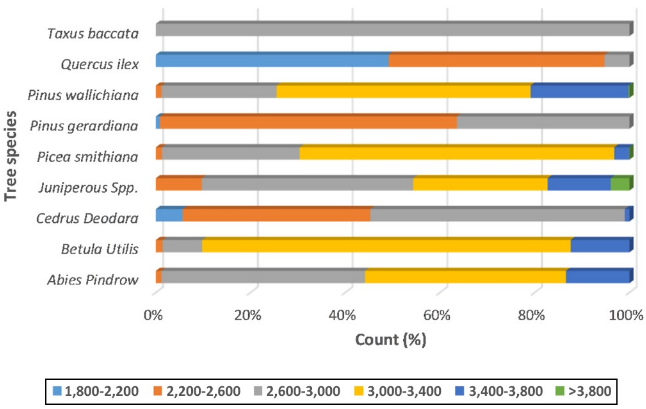

Figure 5.
Species-wise percentage distribution of tree counts according to elevation ranges

et al., 2015; Raqeeb et al., 2014). The present study describes the first detailed forest inventory prepared for the whole of Gilgit-Baltistan. The study was conducted jointly by the Gilgit-Baltistan Forest Department and Pakistan Forest Institute, which planned scientifically to cover as large and representative a forest area as possible without compromising accuracy in data collection and analysis. Precautions were taken to maximize the accuracy of the data; for example, data were re-collected from plots where there was any uncertainty. However, there

Tree species	No. of trees	Average AGB (ton/ha)	Sum	SD	Min	AGB (ton) Average	Max	95% CI	SE
Abies pindrow	1,447	7.23	1,046.81	0.96	0.005	0.72	7.5	0.05	0.03
Betula utilis	911	1.37	124.81	0.1	0.035	0.14	0.61	0.01	0
Cedrus deodara	1,847	16.93	3,126.40	2.75	0.015	1.69	24.8	0.13	0.06
Juniperous Spp.	278	1.96	54.41	0.25	0.02	0.20	1.89	0.03	0.01
Picea smithiana	2,623	13.98	3,666.25	2.14	0.007	1.4	20.72	0.08	0.04
Pinus gerardiana	236	3.73	87.95	0.51	0.004	0.37	3.28	0.07	0.03
Pinus wallichiana	3,953	9.78	3,866.67	1.43	0.005	0.98	18.64	0.04	0.02
Quercus ilex	1,823	4.83	880.98	0.54	0.018	0.48	6.45	0.02	0.01
Taxus baccata	17	4.32	7.34	0.43	0.02	0.43	1.62	0.22	0.10

Table II. Species-wise statistical values of AGB

Tree species	BA (m^2)	RF (%)	RD (%)	RA (%)	IVI (%)
Abies pindrow	135.36	8.39	11.02	10.93	30.34
Betula utilis	41.66	7.16	6.94	3.36	17.46
Cedrus deodara	232.48	10.96	14.06	18.78	43.80
Juniperous Spp.	12.28	6.71	2.12	0.99	9.82
Picea smithiana	325.76	16.89	19.97	26.31	63.17
Pinus gerardiana	15.09	3.13	1.80	1.22	6.15
Pinus wallichiana	371.98	39.71	30.10	30.04	99.85
Quercus ilex	102.54	6.94	13.88	8.28	29.10
Taxus baccata	1.02	0.11	0.13	0.08	0.32
Total	1,238.15	100	100	100	300

Table III. Tree species level BA, RF, RD, RA and IVI

Tree species	No. of stamp	Pi	ln(Pi)	Pi × ln(Pi)
Abies pindrow	1447	0.11	−2.21	−0.24
Betula utilis	911	0.07	−2.67	−0.19
Cedrus deodara	1847	0.14	−1.96	−0.28
Juniperous spp.	278	0.02	−3.86	−0.08
Picea smithiana	2623	0.20	−1.61	−0.32
Pinus gerardiana	236	0.02	−4.02	−0.07
Pinus wallichiana	3953	0.30	−1.20	−0.36
Quercus ilex	1823	0.14	−1.97	−0.27
Taxus baccata	17	0.00	−6.65	−0.01
Total	13,135			

Note: Shannon diversity index (H′) = 1.82

Table IV. Shannon diversity index for nine tree species – Gilgit-Baltistan, Pakistan will always be some level of uncertainty, as there is always a potential for human error, especially when inventorying forests in larger areas (Reese *et al.*, 2003), and there is always room to further improve data collection and processing techniques (Chave *et al.*, 2004).

The field campaigns were conducted in June to October 2015 and 2016 on 556 plots of 0.1 ha (0.04 per cent of total forest area). The rough terrain, long distances, harsh weather conditions and location of forest in steep narrow valleys presented challenges for the field crews, and meant that fieldwork took longer than planned and had to be extended over two seasons. The plots contained 13,135 trees from nine species, more than 80 per cent of them at elevations between 2,200 and 3,400 m (Figures 4 and 5).

A total of nine different tree species were identified across all the sample plots. The Shannon diversity index had a moderate value of 1.82, indicating congenial ecological conditions in which tree communities are thriving, with unequal abundance of different species. Similarly, Simpson's index of diversity (1-*D*) was 0.813, indicating higher diversity within the sample.

The use of new allometric equations for the AGB estimation that were directly derived for the six of the common species in Gilgit-Baltistan was a major step forward. Allometric equations for the same species can vary depending on the ecological (growth) conditions for the trees and need to be locally verified to obtain reliable estimations of AGB. A number of studies conducted at global to national scales (Avitabile *et al.*, 2016; Baccini *et al.*, 2012; Saatchi *et al.*, 2011) suggest that estimation of biomass using intensive field measurements and locally developed allometric equations can substantially minimize the uncertainty in spatial biomass and carbon stock monitoring (Yuen *et al.*, 2016). The allometric equations developed by the Forest Department are primarily applicable to the forest areas of Gilgit-Baltistan but can also be applied in other areas with similar ecological conditions. The best available equations were used for three of the less common species, as they represented only a small proportion of AGB and any error would have had little impact on total values (Table I).

The study focused on measurement of stem and total AGB estimations for trees. The contribution of branches and leaves was not estimated separately, in part because there are no specific allometric equations available for tree components for Gilgit-Baltistan, and general equations would have had to be used. The values derived are appropriate for applications related to large-scale estimates of forest carbon, which have a primary emphasis on the stem or total AGB (Ounban *et al.*, 2016).

Ground-based methods of forest biomass estimation are accurate within the plots sampled but cannot be used to map forest spatial distribution or to prepare biomass estimates over large areas; increasing the number of sample plots can also be difficult because ground-based

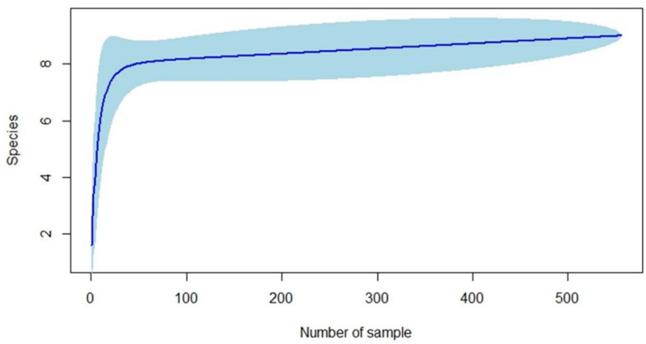

Figure 6.
Species accumulation curve based on total sample plots

methods are often logistically complex. Equally, methods based on remote sensing from satellite platforms can be used to map forest cover over large areas (Houghton, 2005; Lu, 2006; Powell *et al.*, 2010) but cannot be used directly to measure forest biomass, while the steep terrain and complex forest characteristics in mountain areas often affect image interpretation. Combining the two methods offers an effective approach for both mapping forest cover and estimating total biomass over a large area and could also provide an effective way of identifying and monitoring degraded hotspots (Miettinen *et al.*, 2014). Ground measurements are used to train and validate image interpretation and to provide biomass estimates from sample plots; the satellite images provide large-scale maps of forest cover that can be used to guide the sampling process and to extrapolate the plot biomass estimates to the whole area. A number of global initiatives have been reported that aim to map forest biomass using satellite observations (Alvarez-Salazar *et al.*, 2014; Le Toan *et al.*, 2011) and show the promise of the approach. These methods still require ground data for sensor calibration and validation of the products, indicating the continuing need for robust field measurements (Baig *et al.*, 2017). As yet, only one report has been published describing the use of satellite remote sensing data to estimate forest biomass in Pakistan: Ali *et al.* (2011) used satellite pour l'observation de la terre-5 multispectral imagery to estimate forest biomass in Bhurbhan, Punjab. In a later step, the measurements from the present study could be used as a basis for estimating tree biomass for the whole of Gilgit-Baltistan using detailed maps prepared from satellite observations.

The study provides the first detailed results on tree species distribution and biomass in the forests of Gilgit-Baltistan. The most important users of the data will be the policymakers in provincial and federal governments concerned with forest-related decision-making in the context of REDD+ development. Under REDD+, Pakistan has to prepare a National Forest Inventory. The present study contributes substantially to this, not only by providing an inventory for Gilgit-Baltistan but also by describing a detailed approach that can be used in other parts of the country. The biomass tables and equations will help forest resource managers and researchers in Gilgit-Baltistan to accurately estimate the carbon stock and carbon emissions from their forests, and will also help in establishing a subnational-level forest monitoring system. Estimating the biomass in Gilgit-Baltistan's forests using locally developed allometric equations will provide confidence and transparency in estimates of forest reference emission and forest reference levels (FREL/FRL) under REDD+. The Gilgit-Baltistan Forest Inventory can be taken as a reference baseline scenario and will contribute to future REDD+ planning and implementation. Ultimately, the study will contribute towards developing an NFMS in Pakistan and will greatly help in devising national strategies for REDD+. At a broader level, the results of the study will help in identifying sustainable biomass use patterns for livelihood support, forest ecosystem management plans, environmental impact assessment studies, assessment of community forestry and subnational and national carbon monitoring for national and global commitments. For successful implementation of a comprehensive REDD+ program to report FREL/FRL, the relevant authorities in Pakistan need to collect all five pools of biomass, activity data and social dynamics. Limited financial, technical and human capacity and poor institutional setup are major obstacles to achieve equitable REDD+ policy and strategies. Practical implementation of REDD+ will become smooth once such obstacles are effectively addressed.

5. Conclusion

This study represents the first detailed forest inventory carried out for the dry temperate and semi-arid cold region of Gilgit-Baltistan, Pakistan. Although similar studies have been carried out previously in Gilgit-Baltistan, most were limited in scope and restricted to specific areas. The present study covered most of the forest area and had the long-term objective of developing reliable scientific data as a basis for a comprehensive forest inventory. A total of 13,135 trees (DBH ≥5 cm, height ≥2 m) belonging to nine tree species were recorded in the 556 sample plots. More than two-thirds of all trees (68 per cent) were found between 2,600 and 3,400 masl, with 40 per cent above 3,000 masl. The cumulative curve indicates that sufficient area was sampled to provide a reliable picture of the variation in plant species richness and diversity in the Gilgit-Baltistan forest. The initiative is a stepping stone towards future forestry interventions, particularly monitoring of REDD+ activities, at the subnational and the national scale, and provides nationally and globally relevant data for the high-altitude forests of northern Pakistan. These data will contribute to understanding of the changes in natural carbon storage as a result of both human-influenced activities and natural climate variation and biodiversity dynamics in the cold dry mountains of the Hindu Kush Himalayan region.

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