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Development of allometric equation for biomass estimation of *Cedrus deodara* in dry temperate forests of Northern Pakistan

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Key words: Biomass, Carbon, Allometric equation, *Cedrus deodara*, Pakistan.

Abstract

The accuracy of biomass estimates depends on the availability of reliable allometric models to infer biomass of trees from forest inventory data. The current study was undertaken to develop local allomteric equation and biomass expansion factor for *Cedrus deodara*. Data was collected from 32 sample trees which were felled and measured for the study in natural dry temperate forests of Gilgit-Baltistan, Pakistan. Diameter at Breast Height (DBH) and total height of the sample tree were measured before felling. After felling, bole, branches and brushwood were separated and weighed on the spot. Samples were taken from bole, branches and brushwood for drying in the oven at 105° C till they gained constant weight. The allometric equation was developed through logarithmic transformation of dependent and independent variables. Results showed good relationship between biomass as dependent variable and DBH and height as independent variables. The R^2 was found to be 0.98. The F and P values show that the model is significant. Standard Error and sum of square (SS) of the residuals also indicate good fit of the model. The BEF for *Cedrus deodara* varied between 1.17 and 2.07 with a mean of 1.37±0.039 for trees with DBH>20 cm. The percentage contribution of bole, branches and brushwood in the total dry biomass of *Cedrus deodara* was found to be 72.95%, 10.43% and 16.62% respectively. Basic wood density or specific gravity was calculated as 0.46 g/cm^3. The study recommends development of similar allometric equation for biomass estimation of the species in moist temperate forests of Pakistan where climatic conditions are different from the study area.

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Introduction

The emergence of REDD+ (Reducing emissions from deforestation, degradation, sustainable forest management and conserving and enhancing carbon stocks in the forests) as the key mechanism for forest-based climate change mitigation in developing countries necessitates the reliable estimation of total biomass for standing trees in the forests (Agarwall *et al*., 2011). The accuracy of biomass estimates depends on the availability of reliable allometric models to infer oven-dry biomass of trees from forest inventory data (Brown *et al*., 1989; Chave *et al*., 2014). Regression models used to estimate the biomass of the standing trees depend on several variables including diameter at breast height (DBH), total tree height (ht), crown diameter and wood density (ρ) in a given location (Cannell, 1984; Chave *et al*., 2005; Goodman *et al*., 2014). However, the contribution of these variables to the above ground biomass (AGB) differs from site to site, stand structure, disturbance levels and species composition (Whitmore, 1984). Though extensive studies have been conducted to develop allometric equations for biomass estimation of tropical tree species (Brown and Iverson, 1992; Brown, 1997; Chave *et al*., 2005; Litton, 2008), little work has been done for tree species of temperate mountains. As the use of generalized equations can lead to a bias in biomass estimation for a particular species (Cairns *et al.,* 2003, Chave *et al.,* 2005; Litton *et al.,* 2006; Pilli *et al.,* 2006; Litton, 2008), it is important to develop species specific model for accurate estimation of biomass and carbon. In this context, the current study was undertaken to develop allometric equation for *Cedrus deodara*-an important tree species of Pakistan and other countries in the Hindukush Himalayan Region.

Gilgit-Baltistan is situated in the extreme north of Pakistan, bordering China and Afghanistan in the north (35˚-37') and India in the east (72˚-75'), covering an area of 72,496 square kilometers. The whole area falls within the high mountain ranges of Karakorum, Himalayas, Hindukush and Pamir with most of the area situated above 4,500 meters above sea level (Govt. of Pakistan, 2003).

Climatic conditions vary widely in the Gilgit-Baltistan, ranging from the monsoon-influenced moist temperate zone in the western Himalaya, to the arid and semi-arid cold desert in the northern Karakoram and Hindu Kush. Below 3,000 m, precipitation is minimal, rarely exceeding 200 mm annually. However, there is a strong gradient with altitude, and at 6,000 m, the equivalent of 2,000 mm per year falls as snow. Temperatures in the valley bottoms can vary from extremes of 40°C in summer to less than –10°C in winter (Govt. of Pakistan, 2003). The total forest area of Gilgit Baltistan is 337,491 ha. Ecologically most of the forest areas can be classified as dry temperate where *Cedrus deodara* (Deodar) is the dominant species with *Pinus wallichiana* (Kail), *Abies pindrow* (Fir), *Picea smithiana* (Spruce), *Pinus gerardiana* (Chilghoza) and *Quercus ilex* (Oak) as the key associates.

Cedrus deodara locally called as deodar or Himalayan cedar is a magnificent coniferous evergreen tree, 45-60 m tall with a diameter of 0.8 to 1.1 m (Sheikh, 1993. It is the national tree of Pakistan and occupies a dominant position in the dry temperate forests of the country. So far no biomass table or equation has been developed for biomass estimation of *Cedrus deodara*. This study made the first ever attempt to develop local allometric equation for biomass estimation of *Cedrus deodara* in dry temperate forests of northern Pakistan. The allometric model developed in this study can also be used for biomass estimation of the species in other regions with similar ecological conditions.

Materials and methods

Data collection

Data for development of allometric equation was collected during April-August, 2015 through destructive sampling of 32 trees of *Cedrus deodara* scattered in natural forests of Gilgit-Baltistan as shown in the map (Fig. 1). Diameter at Breast height (DBH) of sample trees ranged from 8 cm to 123 cm and their total height ranged from 4.5 m to 42 m. Sample trees were arranged in diameter classes of 5 cm from 6 to 125 cm.

For determination of height functions, additional trees were measured to cover any variation in height due to site quality, slope and aspect. 2-3 sample trees per DBH class were randomly selected, felled and measured for data collection.

Efforts were made to select trees of normal form and shape to closely represent the forest stands of the area. Trees with broken top, forked stem, excessive or less branching or any other abnormality were avoided.

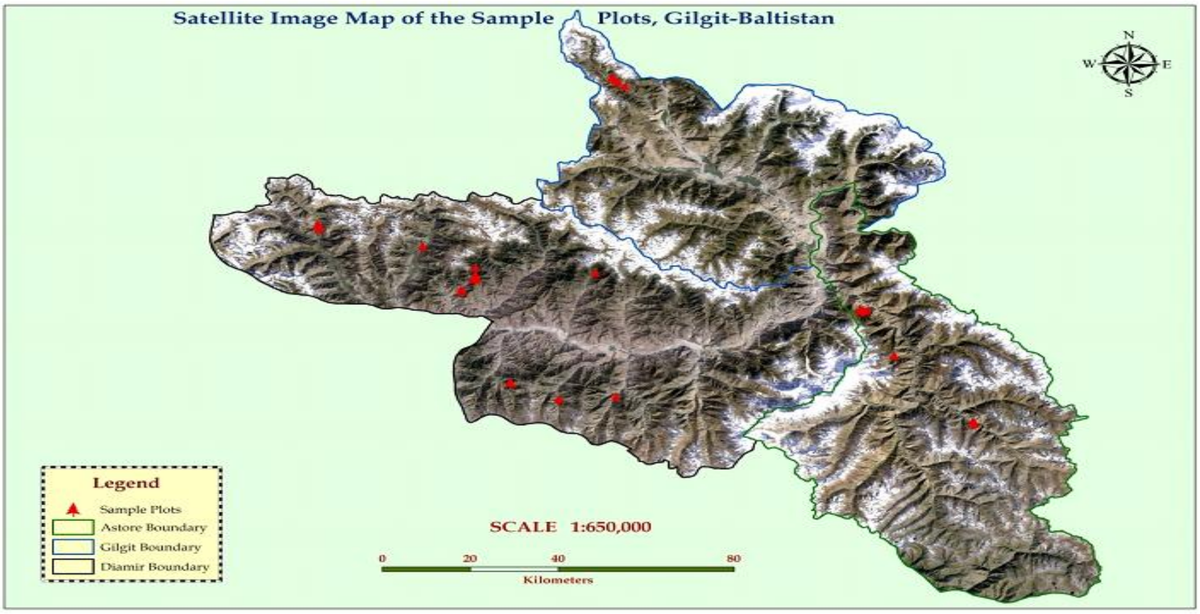

Fig. 1. Location of sample trees.

Diameter at Breast Height (DBH) and total height of the sample tree were measured before felling. Point of DBH was marked on stem at 1.37 m (4.5 feet) aboveground on uphill side and DBH was measured with dia tape upto one decimal in centimeter.

Total height of the standing tree from ground to tip of the leading shoot was measured in meters upto two decimals with clinometer or relaskop. The sample trees were felled with the help of a chain saw as close to the ground as possible in a pre-decided direction to minimize damage to other trees.

After felling, the branches and leaves were removed from the stem. Small branches upto 5 cm diameter at thin end were separated. Brush wood- branches with dia less than 5 cm alongwith leaves/needles- was separated. Fresh weight of branches and brushwood were recorded separately. Samples were taken from branches and brushwood and packed in bags for oven drying in the Laboratory at Pakistan Forest Institute. The stem was converted into 2 m logs with end log of variable length.

The over bark mid diameter of the log and its length were measured for determining volume of logs using Huber's formula as below:

Volume= $\pi(D^2/4)*L$

Where D is diameter over-bark at midpoint and L is length of log.

The fresh weight of each log was measured on the spot with the help of a digital weighing machine.

However, some of the logs were too heavy to be lifted and directly weighed on the scale, so small discs were cut from the logs. Volume and fresh weight of these discs were determined on the spot and these discs were brought to laboratory for oven drying. The densities of the discs were applied to the volume of the logs to determine their biomass.

The samples of boles, branches and brushwood and bark were dried in the oven at 105°C until they attained a constant weight.

The dry to fresh weight ratios were applied to calculate the dry biomass of stems, branches and brushwood of the whole tree. The significance of allometric equation was checked by applying the F-test and t-test. The statistical analysis was carried out through SPSS 16 and Microsoft Excel.

Model fitting

Several allomteric equations have been developed by researchers to estimate biomass of different tree species using several variables as predictors or independent variables. DBH, total height, volume, basal area, density and crown radius are the common variables used for estimation of tree biomass (Chave *et al*., 2005; Mandal *et al*., 2013; Goodman *et al*., 2014). However, DBH is the most commonly used independent variable for biomass estimation due to ease in measurement and being strongly correlated with tree volume and biomass. DBH alone can be used as a single biomass predictor in allometric models . When combined with other variables such as total height and density the estimates could be improved in some cases.

Different regression models were evaluated for their reasonability, efficiency, practicability and statistical validity. A model is considered reasonable if it yields estimates with minimum standard error (SEE), minimum sum of square of the residual error (SSE) throughout the range of data, does not give negative estimates and does not show decrease in biomass with increase in D or H (Ahmad and Husain, 1994). The equation is considered efficient if it yields accurate estimate and controls the bias. The estimates beyond the range of data i.e. extrapolated values should not be unrealistic or exaggerated. The equation is practicable if it is easy to calculate and use meaning that the equation should not depend on a large number of variables. Statistical validity is judged on the basis of the 'indices of best fit' including R^2 which is the determination coefficient and can be interpreted as being the ratio between the variance explained by the model and the total variance. It is between 0 and 1, and the closer it is to 1, the better the quality of the fit.

On the other hand, SSE and SEE should be minimum whereas F and P values of the models should be significant.

All regression models used for biomass estimation are based on three hypotheses- the residuals are independent, follow a normal distribution and have constant variance (Picard *et al*., 2012). The hypothesis that the residuals are normally distributed can be checked visually by inspecting the quantile–quantile graph which shows the empirical quantiles of the residuals against the theoretical quantiles of the standard normal distribution. If the points are approximately aligned along a straight line, then the hypothesis is satisfied. The hypothesis of constant variance can be checked visually by plotting the cluster of points for the residuals against predicted values. If the variance of the residuals is indeed constant, this cluster of points should not show any particular trend or structure (Picard *et al*., 2012).

Biomass Expansion Factor (BEF) was determined from the sample trees felled for development of allometric model. BEF was calculated as below:

$$BEF = M_{ag}/M_b$$

where M_{ag} is the total above-ground dry biomass of a tree and M_b is the dry biomass of the tree bole with top diameter upto 5 cm.

Basic wood density or specific gravity of *Cedrus deodara* was determined during the current study. For this purpose three to five discs of 10 cm thickness were taken from base, middle and top of the bole of every sample tree.

These discs were marked with tree No. and section No. (S_1, S_2, S_3) before taking their fresh weights. The fresh weight of each disc was measured in grams with the help of a digital balance in the field. The volume of the discs were measured in cubic centimeter through water displacement method in the Xylometer. The discs were dried in the oven at 105° C till they gained constant weight. After drying in the oven, the weights of the discs were measured.

The Basic Wood Densities of the discs were calculated by the following formula:

Density of specimen = Dry Weight in gm/Fresh Volume in cc.

Basic wood densities were recorded in gram/cubic centimeter.

Results and discussions

Biomass model

The allometric equation was developed through logarithmic transformation of dependent and independent variables which is given below:

$M= 0.1779(D^2H)^{0.8103}$ or $M = \exp\{- 1.7264+0.8103 \mathrm{Ln}(D^2H)\}$

Where

M = Aboveground Dry Biomass of tree in Kg

D = Diameter at Breast Height in cm

H = Total height of tree in m

Ln = Natural Logarithm.

The pictorial representation of the model is shown in Fig. 2 and 3. Results showed good relationship between biomass as dependent variable and DBH and height as independent variables. The R^2 was found to be 0.98. The F and P values show that the model is significant. Standard Error and sum of square (SS) of the residuals also indicate good fit of the model (Table 1).

Table 1. Statistics of regression equation.

Allometric equation	Standard Error	F value	P value	SS of Residuals	R^2
$M= 0.1779(D^2H)^{0.8103}$ or $M = \exp\{- 1.7264+0.8103\mathrm{Ln}(D^2H)\}$	0.183	1929	0.000	1.010	0.985

The residuals plot (Fig. 4) shows that the residuals are scattered around the zero and do not show any trend or structure confirming the hypothesis of constant variance of the residual error.

Similarly, Q-Q plot shows that the residuals are normally distributed as the points are approximately aligned along a straight line as shown in Fig. 5. These graphs show the model is good fit for its applicability.

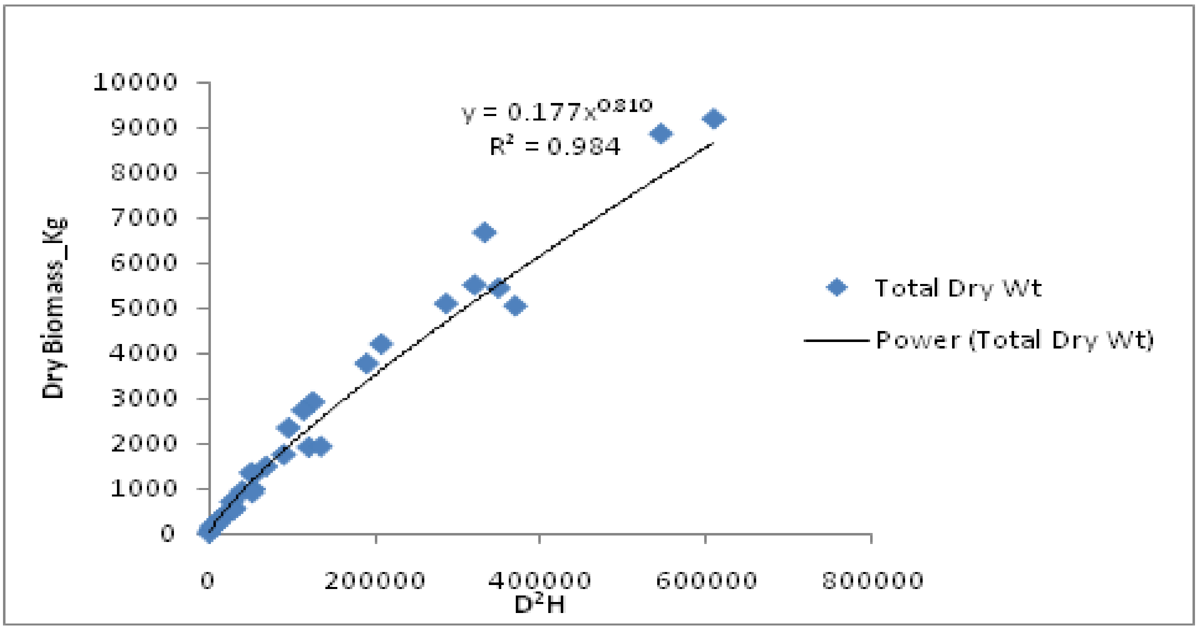

Fig. 2. Deodar Biomass Regression Model.

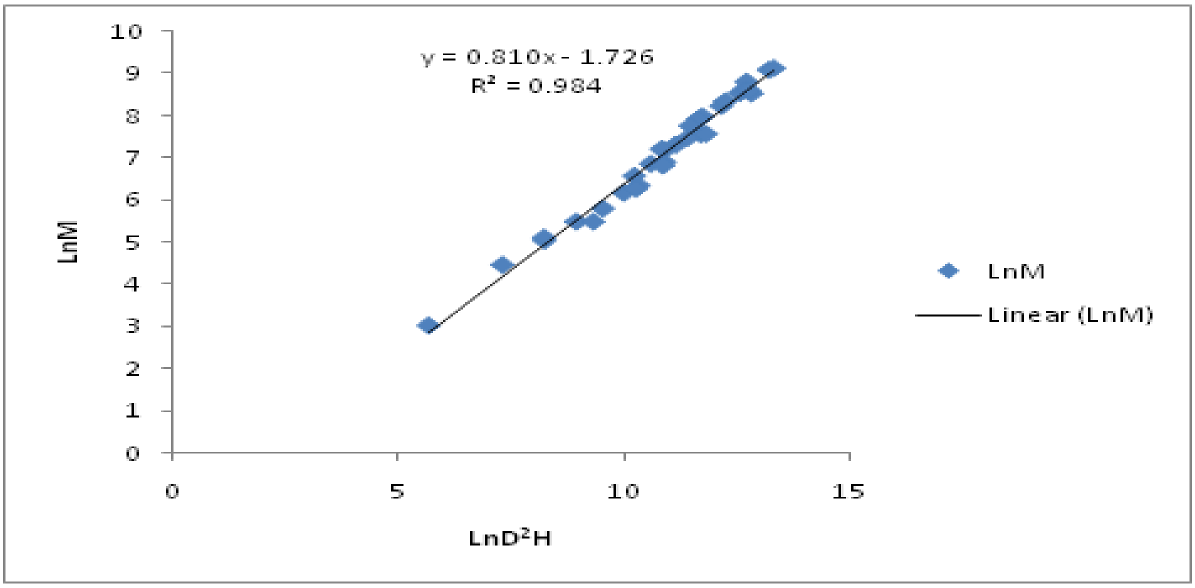

Fig. 3. Deodar Biomass Regression Model (Log Transformed).

The results of the study are in conformity with Chave *et al.* (2005) who developed the equation $M= 0.112(pD^2H)^{0.916}$ for dry tropical forests. They included wood density (p) as additional variable in the model as their model was meant for a mixture of tree species whereby wood density varies from species to species.

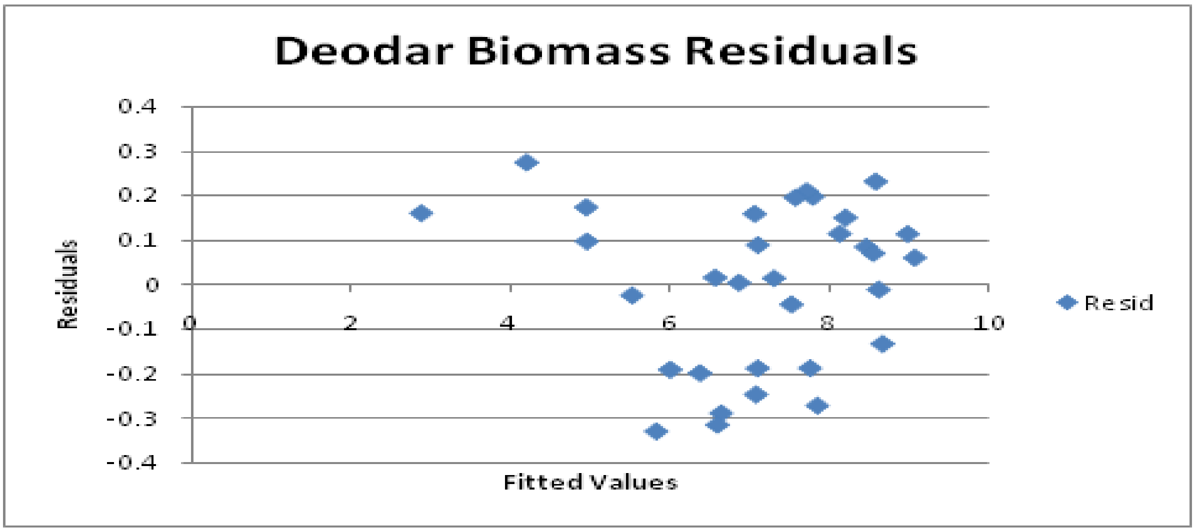

Fig. 4. Scatter Plot of Deodar Biomass residuals.

However, in case of our model wood density did not improve the performance of the model and hence not included. Other researchers (Brown *et al.*, 1989; Mandal *et al.*, 2013) have also found that the variable D^2H was a suitable predictor of total tree biomass.

The Biomass Expansion Factor (BEF) for *Cedrus deodara* varied between 1.17 and 2.07 with a mean of 1.37±0.039 (95 percent confidence interval) for trees with DBH>20 cm.

These results can be compared with findings of Levy *et al.*, 2004 who determined BEF for the coniferous species of the Great Britain as 1.04-2.32 with a mean of 1.43 ± 0.008. The percentage contribution of bole, branches and brushwood in the total dry biomass of *Cedrus deodara* was found to be 72.95%, 10.43% and 16.62% respectively. Basic wood density or specific gravity was calculated as 0.46 g/cm^3.

The finding is in conformity with Siddique *et al.* (1996) who determined air dry wood density of the species as 0.560 g/ cm^3.

As air dried wood contains 10-12% moisture and oven dried wood has 1-2% moisture, the value of air dry density is higher than oven dry density.

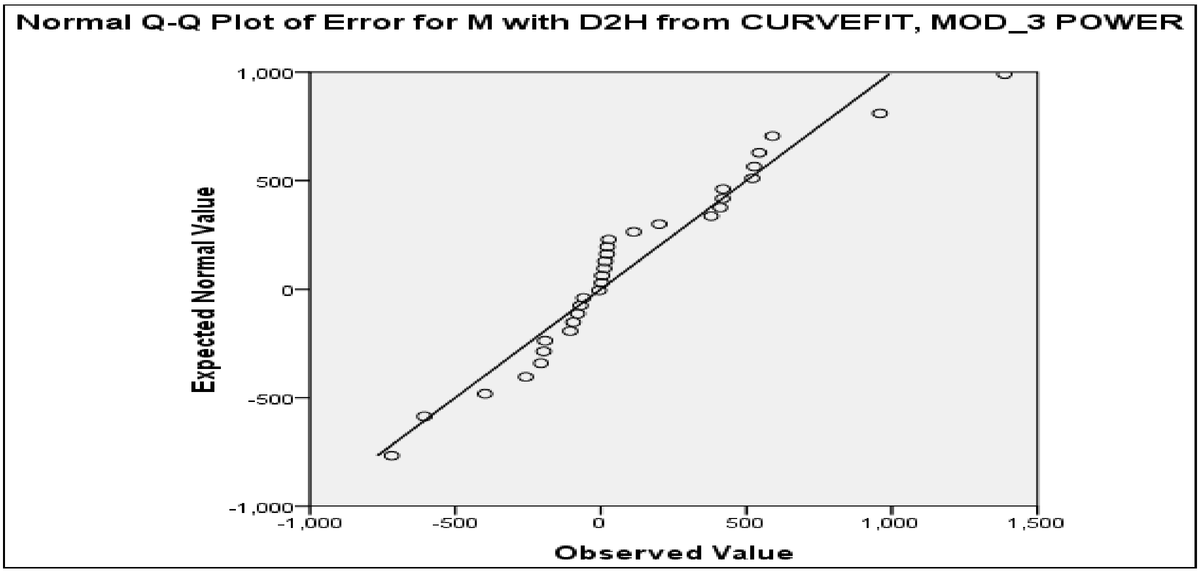

Fig. 5. Q-Q Plot of Deodar Biomass Residuals.

As *Cedrus deodara* is also found in moist temperate forests of Pakistan where ecological conditions are different than the study area and the species may exhibit different growth pattern, it is recommended that similar model may be developed for moist temperate forests.

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