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Assessment of Biomass Content and Oxygen Production from Tree of Subtropical Area

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ABSTRACT

The accurate classification of tree species is critical for the management of forest ecosystems, particularly subtropical forests, which are highly diverse and complex ecosystems. While airborne Light Detection and Ranging (LiDAR) technology offers significant potential to estimate forest structural attributes, the capacity of this new tool to classify species is less well known. In this research, full-waveform metrics were extracted by a voxel-based composite waveform approach and examined with a Random Forests classifier to discriminate six subtropical tree species (i.e., Masson pine (*Pinus massoniana* Lamb.)), Chinese fir (*Cunninghamia lanceolata* (Lamb.) Hook.), Slash pines (*Pinus elliottii* Engelm.), Sawtooth oak (*Quercus acutissima* Carruth.) and Chinese holly (*Ilex chinensis* Sims.) at three levels of discrimination. As part of the analysis, the optimal voxel size for modelling the composite waveforms was investigated, the most important predictor metrics for species classification assessed and the effect of scan angle on species discrimination examined. Results demonstrate that all tree species were classified with relatively high accuracy (68.6% for six classes, 75.8% for four main species and 86.2% for conifers and broadleaved trees). Full-waveform metrics (based on height of median energy, waveform distance and number of waveform peaks) demonstrated high classification importance and were stable among various voxel sizes. The results also suggest that the voxel based approach can alleviate some of the issues associated with large scan angles.

KEYWORDS: *tree, subtropical, biomass, oxygen, classification, median, sizes, species*

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INTRODUCTION

The impact of hydrologic regime shifts in the Asian Monsoon under changing global climate is significant, since the intensity of monsoon directly affects the agricultural production of the most densely populated regions in the world[1]. Proxy climate records dating back to the pre-instrumental era are therefore essential for evaluating the roles of natural variability and anthropogenic impact on the Asian Monsoon system. Tree rings have often been used to reconstruct past climate variations with annual resolution, and extensive networks of tree-ring chronologies have been developed in North America and Europe. Unlike in higher latitudes, relatively few tree-ring chronologies were produced for tropical and subtropical Asia, since the lack of climatic seasonality hinders annual ring formation of most tree species in these regions. However, over the last couple of decades dendrochronologists[2] have found increasing success in the low latitudes of Asia by selecting regions with more pronounced temperature or precipitation seasonality. A major recent advance has been the hydroclimatic reconstructions from rare and long-lived Fujian Cypress (Fokienia hodginsii) growing in Vietnam (Buckley et al. 2010; Sano et al. 2009). These records based on ring width measurement revealed that the region experienced decadal-scale droughts in the past, which have no analog in the instrumental period. [3] Interestingly, these exceptional droughts coincided with periods of social unrest (Buckley et al. 2010). In addition to this progress, other recent studies indicated that oxygen isotope ratios of tree-ring cellulose might help improve our understanding of monsoon activity (Sano et al. 2012a,b ; Xu et al. 2011). In this brief note, we show some advantages of using tree-ring δ18O rather than ring width and wood density traditionally utilized in dendroclimatolgy.

It is well known that tree-ring width and wood density are controlled not only by climate but also by endogenous disturbance pulses, such as competition with neighboring trees. To reduce such disturbances, climatically sensitive trees are sampled predominantly at the species ecological boundaries, such as near arid or cold forest limits. This spatial limitation can be overcome by using oxygen isotope ratios,[4] since the isotopic ratio in the wood is not significantly affected by ecophysiological processes. Tree-ring δ18O is theoretically controlled by two climatic factors, δ18O of the source water and relative humidity (e.g. Robertson et al. 2001; Saurer et al. 1997), both of which are closely related to monsoon activity in South and Southeast Asia. Our preliminary analyses using samples from the Himalayas (Sano et al. 2010) and Laos (Xu et al. 2011) clearly show that tree-ring δ18O is more strongly correlated with precipitation, relative humidity, temperature and Palmer Drought Severity Index (PDSI) than is ring width or wood density. PDSI is a drought metric based upon a water balance model. Positive and negative values of the PDSI correspond respectively to wet and dry conditions (Palmer 1965; Dai et al. 2004). Tree-ring δ18O from the Nepal Himalayas accounts for 34% of the inter-annual variability of the PDSI in the monsoon season (July–September), and clearly shows a decreasing trend of precipitation/moisture over the last two centuries. Evidence for a decrease in summer monsoon rainfall was also found in δ18O of tree rings from Tibet (Grießinger et al. 2011), δD of an ice core from Mt. Everest (Kaspari et al. 2007), snow accumulation of an ice core from Dasuopu, Tibet (Zhao and Moore 2006), and varve thickness of lake sediments in Tibet (Chu et al. 2011). The overall trends toward arid conditions indicate that summer monsoon has weakened across wide areas of the Himalayas and Tibet for at least the last couple of centuries.[5]

Our reconstructed PDSI shows significant correlations with sea surface temperatures in the tropical Pacific and Indian Ocean, suggesting that the tropical oceans play a role in modulating hydroclimate in the Nepal Himalayas. A simulation model forced by observed sea surface temperature (SST) data reveals that a weakening trend of monsoon precipitation found in northern India and the eastern Tibetan Plateau over the latter half of the 20th century is deducible from the atmosphere's response to an increase in SSTs over the tropical Pacific and Indian Ocean (Zhou et al. 2008). Therefore, the consistent warming found in reconstruction of tropical SSTs over the last two centuries (Wilson et al. 2006) might be responsible for the weakening monsoon in the Himalayas.[6] In contrast, other proxy records from lower altitudes indicate a strengthening of the monsoon winds (Anderson et al. 2002) and precipitation (Wang et al. 2005). The increased north–south difference of monsoon activity is likely induced by a southward shift in the overall position of the monsoon trough. In contrast to ring-width-based reconstructions from the Himalayas and Tibet, those from Southeast Asia are rare, since most trees grow in relatively warm and wet environments.[7] To overcome this limitation, isotopic analyses have been conducted on samples from four cypress trees from Laos for the past 52 years (1951-2002). It turned out that contrary to the tree-ring widths data (Xu et al. 2011), the δ18O time series of the trees are significantly correlated with each other. Also, the δ18O chronology built from the four trees shows significant correlation with temperature ($r = 0.64$, $p < 0.001$), precipitation ($r = -0.34$, $p < 0.05$) and PDSI ($r = -0.66$, $p < 0.001$) in the monsoon season. In contrast, no significant correlation was found between any climatic variables and a ring-width chronology based on 15 trees, which includes the four trees utilized for the isotope measurement. Finally, the δ18O chronology is strongly correlated with ENSO-related indices, particularly with the Multivariate ENSO Index (MEI; Wolter and Timlin 2011) for the last 52 years. To further explore the potential of isotope dendroclimatology, six more cypress trees from Vietnam have been subjected to δ18O analyses. Surprisingly, the δ18O chronology from Vietnam is closely correlated to that from Laos (Sano et al. 2012b), even though these sampling sites are around 150 km away from each other. Moreover, the teleconnected relationships between the δ18O chronology and ENSO-related indices are stable over the 135-year period of available instrumental data.[8]

Over the last decade, considerable effort has been devoted to reconstruct ENSO variability using tree rings and other proxy records that originate mainly from North America and the topical Pacific (e.g. D'Arrigo et al. 2005; Mann et al. 2000; Wilson et al. 2010). Although these records agree well during the twentieth century, there is relatively little agreement before this time. Wilson et al. (2010) point out that the teleconnected relationship between the tropical central/eastern Pacific and regions where proxy records are located does not seem to be stable. Since none of the previously published reconstructions of

ENSO variability include data from mainland Southeast Asia, tree-ring δ18O is of great use to independently reconstruct ENSO, and to explore the spatial influence of ENSO before the instrumental period.[9]

Discussion

Forests are the world's largest carbon sink and play a vital role in climate change mitigation through carbon sequestration; thus the assessment of carbon stock in the forests is important for policy prescription and management planning. In view of this, present study is an attempt to assess the biomass and carbon stock of tree species in selected subtropical and temperate forest stands along the vertical elevation gradient (300 m to 2250 m) in the Central Himalaya. Volumetric equations (allometric method) were used for various tree species along with field sampling/ assessment (quadrat method) for biomass and carbon sequestration potentials. The total tree biomass and carbon stock of dominant forest stands varied from 227.23 to 577.16 Mg ha−1 (megagram per hectare), and 107.93 to 274.15 Mg C ha−1 respectively; it was found maximum for Sal (*Shorea robusta*) dominated forest and minimum for mixed Oak forest (*Quercus floribunda, Q. lanuginosa, Q. leucotrichophora* etc.). The carbon sequestration was recorded maximum (4.83 Mg C ha−1 yr−1) for Chir-pine stand (*Pinus roxburghii*) followed by Sal (4.63 Mg C ha−1 yr−1), mixed Oak (4.47 Mg C ha−1 yr−1), and minimum (3.99 Mg C ha−1 yr−1) for temperate Banj-oak forest (*Quercus leucotrichophora*). The contribution of above and below ground biomass among different forest stands was recorded 82% and 18% respectively. The dominant species contributed maximum biomass and carbon stock (70–82%) in pure Sal, Chir-pine and Banj-oak stand, while the contribution of dominant and co-dominant species in the mixed forest varied depending on forest composition.[10] The results reveal higher carbon stock for subtropical forest as compared to temperate forest; however, it is interesting that there is no significant difference in carbon sequestration among the different forest stands. The study recommended for the assessing biomass and carbon stock of different forests for long-term management of forests and climate change mitigation.[11]

Tree biomass and species diversity have a key role in regulating proper ecosystem functioning. The present study explored variability among four Sal (*Shorea robusta* Gaertn. f.) forest stands of Bhabar belt of Nainital district of Uttarakhand, Central Himalaya within an elevational range of 405–575 m. Quadrat method was used for sampling to assess the phytosociology and allometric regression equations for biomass and carbon stocks. Significant differences were observed among forest stands in terms of structural attributes. The study sites catalogued 26 tree species with highest species richness on site Ranibagh (RB). Tree density ranged in between 620 individuals ha− 1 [site Fatehpur (FP)] and 810 individuals ha− 1 (site RB). The Kaladhungi (KD) site yielded maximum biomass (317.60 Mg ha− 1) followed by site FP (274.05 Mg ha− 1), site RB (248.62 Mg ha− 1) and least (221.46 Mg ha− 1) by site AP (Amritpur). The maximum carbon stock (244.82 Mg C ha− 1) was recorded on site AP, followed by site KD (150.86 Mg C ha− 1), site FP (130.18 Mg C ha− 1) and site RB (116.91 Mg C ha− 1). The maximum biomass and carbon stock (61.09–92.23%) was endowed by dominant tree species (S. robusta). The aboveground components among forest stands contributed 71.84–77.23%, while belowground biomass contributed 26.76–27.24% to the total biomass. The sub-tropical forests across Central Himalayan regions have been modified by biotic interferences that alter the ecosystem structural and functional aspects including plant diversity, nutrient cycling and productive traits. Thus, assessing the variability in phyto-sociological parameters of forests is important for planning well- structured and precise forest management regimes.[12]

Results

Forest ecosystems are an integral component of the global carbon cycle as they take up and release large amounts of Cover short time periods (C flux) or accumulate it over longer time periods (C stock). However, there remains uncertainty about whether and in which direction C fluxes and in particular C stocks may differ between forests of high versus low species richness. Based on a comprehensive dataset derived from field-based measurements, we tested the effect of species richness (3–20 tree species) and stand age (22–116 years) on six compartments of above- and below-ground C stocks and four components of C fluxes in subtropical forests in southeast China. Across forest stands, total C stock was 149 ± 12 Mg ha^{-1} with richness explaining 28.5% and age explaining 29.4% of variation in this measure. Species-rich stands had higher C stocks and fluxes than stands with low richness; and, in addition, old stands had higher C stocks than young ones.[13] Overall, for each additional tree species, the total C stock increased by 6.4%. Our results provide comprehensive evidence for diversity-mediated above- and below-ground C sequestration in species-rich subtropical forests in southeast China. Therefore, afforestation policies in this region and elsewhere should consider a change from the current focus on monocultures to multi-species plantations to increase C fixation and thus slow increasing atmospheric CO_2 concentrations and global warming. Previous biodiversity–productivity studies in forest ecosystems reported positive effects of tree species richness on above-ground components of primary productivity, suggesting that more C might be stored in species-rich forests. We found more C below than above ground in our subtropical forests, raising the question whether richness effects might be changed if total rather than only above-ground C storage is considered. Our findings demonstrate that indeed total above- and below-ground C storage in subtropical forest increases with species richness if major components of C fluxes and C stocks are considered. At the regional scale, subtropical forests in southeast China are a major potential C sink because of the implementation of large afforestation and plantation programmes in the last 36 years. However, these plantations were mainly established with single species and even though they will continue to accumulate C if their continued growth can be maintained into the future, much larger amounts of C could have been stored according to our study if plantation programmes would have adopted multi-species planting schemes.[14]

Conclusions

Assuming a total amount of 30.3 Tg C stored per year by the planted monoculture forests in China tentatively valued at 0.4 billion dollar, and extrapolating our results to other types of forests, an additional 6.4% C ha^{-1} could have been stored per year for every additional species. As a consequence, amounts in the order of 0.3 billion dollars per year (0.4×0.064^9) might have been gained by using 10-species mixtures instead of monocultures for the 0.89×10^6 ha of planted forests in China. This assumes that the relationship between monocultures and 10-species mixtures has a similar slope to the one we found here between three- and 20-species mixtures. At the same time, this indicates the potential gains that could still be realized by switching to species-rich plantation schemes now. Such plantation schemes may be costly to carry out but could have the additional advantage that species-rich forests can be expected to be more stable and resistant to global change and to extreme events, and they contribute to biodiversity maintenance. Therefore, biodiversity should be considered as an integral component in forest-carbon management strategies.[15]

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