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Short Communication

An indirect method of estimating leaf area index in a tropical deciduous forest of India

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ABSTRACT

Rapid, reliable and meaningful estimates of leaf area index (LAI) are essential to functional characterization of forest ecosystems including biomass and primary productivity studies. Accurate LAI estimates of tropical deciduous forest are required in studies of regional and global change modeling. Tropical deciduous forest due to higher species richness, multiple species association, varied phenophases, irregular stem densities and basal cover, multistoried canopy architecture and different micro-climatic conditions offers dynamism to the understanding of the LAI dynamics of different PFTs in an ecosystem. This investigation reports a new indirect method for measurement of leaf area index (LAI) in a topical moist deciduous forest in Himalayan foothills using LAI-2000 Plant Canopy Analyzer. We measured the LAI in two seasons (summer; leaf senescence stage and post-monsoon; full green stage) in three (dry miscellaneous, sal mixed and teak plantations) plant functional types (PFT) in Katerniaghat Wildlife Sanctuary, India. Ground LAI values ranged between 2.41 and 6.89, 1.17 and 7.71, and 1.92 and 5.19 during post-monsoon season and 1.36–4.49, 0.67–3.1 and 0.37–1.83 during summer season in dry miscellaneous, sal mixed and teak plantation, respectively. We observed strong correlation between LAI and community structural parameters (tree density, basal cover and species richness), with maximum with annual litter fall ($R^2 > 0.8$) and aboveground biomass (AGB) ($R^2 > 0.75$). We provided equations relating LAI with AGB, which can be utilized in future studies for this region and can be reasonably extrapolated to other regions with suitable statistical extrapolations. However, the relations between LAI and other parameters can be further improved with incorporation of data from optimized and seasonal sampling. Our indirect method of LAI estimation using litter fall as a proxy, offers repetitive potential for LAI estimate in other PFTs with relatively time and cost-effective way, thereby generating quicker and reliable data for model run for regional and global change studies.

1. Introduction

Rapid, reliable and meaningful estimates of leaf area index (LAI) are essential to the functional characterization of forest ecosystems. The leaf area is the exchange surface between the photosynthetically active component of the vegetation and the atmosphere (Cohen et al., 2003; Chen et al., 1997; Chen and Cichlar, 1995), which controls not only the radiation regime within the canopy, but also the thermal and hydric conditions (Chen et al., 2009). LAI is a key variable in driving the biological processes of the plants, thus is a necessary input variable in many ecological models studying canopy structure and productivity (Norman and Campbell, 1989; Welles and Norman, 1991; Chen et al., 2009). LAI is mostly directly proportional to transpiration and net primary production (NPP), and inversely proportional to canopy transmissivity (Whitehead et al., 1984; Zhou et al., 2002; Asner et al., 2003). LAI is influenced by elevation (or temperature), water availability, soil fertility and topography, and much of these studies are from temperate biomes (Leuschner et al., 2007). However, comprehensive studies on LAI from tropical complex forest ecosystems are less in number.

Leaf area index (LAI) is a dimensionless variable and is defined as the total one-sided area of photosynthetic tissue per unit ground surface area (Watson, 1947), and thus is strictly applicable for broad-leaved trees with flat leaves since both sides of a leaf have the same surface area. However, if foliage elements are not flat (i.e., wrinkled, bent or rolled) or for coniferous trees wherein

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needles may be cylindrical or hemi-cylindrical, the one-sided area is not clearly defined (Chen and Black, 1992), a projected leaf area is taken into account for the irregular form of needles and leaves (Smith et al., 1991; Bolstad and Gower, 1990). LAI measurements can be performed by two methods: direct and/or indirect. Direct measurements through harvesting and litter traps are laborious and impractical; though, they can be used to calibrate indirect methods. Most field campaigns utilize indirect measurements of LAI through allometric and optical methods. Optical measurements are performed with the LAI-2000 Plant Canopy Analyzer, Tracing Radiation and Architecture of Canopies (TRAC) instrument, and hemispherical fisheye photographs. Even though direct destructive measurements of LAI are widely believed to be more accurate than indirect optical estimates, the LAI-2000 system has proven to provide LAI measurements closest to those obtained with leaf harvest methods in tropical forests (Asner et al., 2003).

LAI can be estimated indirectly from the incident radiation transmitted through the canopy at a given zenith angle using a number of instruments (LAI-2000, DEMON, Ceptometer, hemispherical photography), known as 'gap fraction' method (Chen et al., 1997; Li-Cor, 1992). The problems with 'gap fraction' method are (i) branches and stems contribute to the intercepted light, and (ii) LAI estimation assumes a random distribution of foliage elements, while in reality the spatial distribution of leaves depends on the distribution of shoots, branches and tree crowns. However, Optical measurements of LAI could also be biased because they (i) do not account for clumping of vegetation elements (e.g., LAI-2000 measurements) or, (ii) do it in a semi-empirical way (TRAC measurements) (Welles and Cohen, 1996). Vegetation clumping and saturation of the optical signal reduce the accuracy of LAI measurements in high LAI stands (mostly in broadleaf forests); and also automated processing of optical LAI measurements does not distinguish between green leaves and hardwood material. The removal of such effects is tedious with manual images processing and thus or requires specific allometric relations to convert plant area index to LAI. Since the clumping index varies with the zenith angle, the gap fraction is easily measured at different zenith angles by LAI-2000 PCA. In deciduous forests, the same gap fraction method that is used for estimating LAI can be used for measuring the effective woody area index during the non-vegetative season, when the leaves are shed. The size of the non-green elements of the trees does not vary much within the season than between the growing and non-growing season due to exposure of branches during leaf fall.

Tropical deciduous forest due to higher species richness, multiple species association, varied phenophases, irregular stem densities and basal cover, multistoried canopy architecture and different micro-climatic conditions, offers dynamism to the understanding of the LAI dynamics of different PFTs in an ecosystem (Blackburn and Gaston, 1996; Behera et al., 2012). We aimed to establish an indirect method for LAI estimation using LAI-2000 PCA. We also tried to analyze the relation between LAI with community, as well as structural and functional variables such as species richness, basal cover, stem density, litter fall and above-ground biomass in three PFTs having distinct tree species compositions, different carbon assimilation rates and micro-climate conditions in a tropical deciduous ecosystem along Himalayan foothills. Additionally, we attempted to establish the relationship between in situ LAI and the annual litter fall, and to predict aboveground biomass (AGB) from ground measured LAI for each PFTs.

2. Methodology

2.1. Study area

The present study was undertaken at Katerniaghat Wildlife Sanctuary (KWLS), a representative tropical deciduous forest in the upper Gangetic plains adjoining Himalayan foothills in Uttar Pradesh state, India (Fig. 1). The KWLS is situated between 27°41′ and 27°56′ N latitude; and 81°48′ and 81°56′ E longitude, with elevation ranges from 116 to 165 m along the southern border of Nepal. It is a dense patch of 40 km long and 10 km wide with an area of 440 km^2. The site experiences climatic variation, typical of northern India with extremes of heat and cold; and winter nights are very cold and foggy and heavy dew falls regularly. The nights remain cool and dew falls until late in the spring, the hot weather commencing in April and lasting until the rains break toward the end of June. Heavy monsoon rain is experienced from June end to September, and along with the winter rainfall an average annual rainfall of about 1300 mm is experienced.

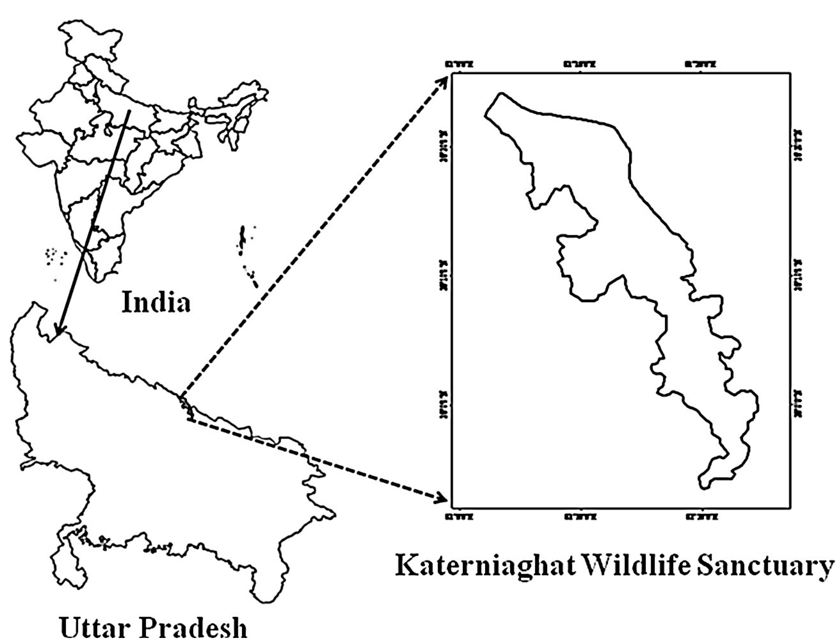

Fig. 1. Location map of Katerniaghat Wildlife Sanctuary, Uttar Pradesh, India.