Summary of Thesis

Modelling of NPP over Tropical Deciduous Forest using Meteorological and Satellite Data

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Terrestrial net primary production (NPP), the time integral of the positive increments to plant biomass, is the central carbon-related variable summarizing the interface between plant and other processes. It describes both the removal of carbon from the atmosphere and the potential delivery of carbon to herbivores, decomposers, or humans interested in food or fiber. As a principal indicator of ecosystem health, resource utilization, and biospheric carbon fluxes, NPP is of great importance to ecological studies, natural resource management, and estimates of the terrestrial carbon sink. India rank 10^{th} amongst the most forested countries of the world with 20.6 percent (77.82 Mha) of its geographical area under forest and tree cover. Of which, maximum area (15 %) comprised by deciduous forest. However, net carbon exchange between the forest and the regional atmosphere has been little studied. Thus an accurate assessment of carbon fixation in the ecosystem is fundamental for realistic global and regional carbon budgets and for projecting how these will be affected by changing climate and atmospheric composition. To overcome this circumstance reliable biogeochemical model is indispensable. Field measured NPP and remote sensing derived NPP data are further needed for validating and calibrating global biogeochemical models. Field data on the relation of tropical forest NPP to these factors are needed to resolve these uncertainties. Such data will also be important for assessing the carbon-sequestering potential of these forests and as benchmarks for carbon offset agreements involving tropical countries. Keeping the aforesaid perspectives in the mind, the study has been carried out by modelling NPP in tropical deciduous forest using satellite and meteorological data. Study has been also carried out to understand the influence of regional weather parameters on NPP of the forests.

In general estimating or modelling deciduous forests NPP and its interaction with climatic parameters is seriously inhibited in KNP, BNP and MNP due to lack of adequate observational data or due to significant uncertainties in model parameterisation and validation, such as NPP from field measurements. The challenge to forest researchers who are inquisitive to know the spatial variability of NPP in these parks and to know its relation with climate parameters, are need to carry out extensive regular forest growth measurements and weather data recording and their analyses in a consistent manner. A limitation to our

knowledge about the moist deciduous and dry deciduous forests productivity patterns in these national parks is that relatively few studies are longer than a single year. Some of the studies (Kale and Roy, 2012; Christian et al., 2015) showed spatial distribution of NPP in dry deciduous forests of MNP, but not documented its relation with climate parameters. If climatic parameters exert strong control on deciduous forests NPP, then variation in annual and seasonal precipitation potentially drives inter-annual variability in NPP of these forests. The long-term implications for this variability relate to the ability of forest stands to respond to changing climatic conditions. Therefore, it is extremely important to monitor deciduous forests as important natural resources in developing countries like India. An accurate and regularly updated biome specific resource data is a prerequisite for the present-day forest ecosystem management to understand their quantitative contribution to the regional/global carbon budgets and for projecting how these forests will be responding to changing climate. Assessing the health and function of deciduous forest ecosystems essentially requires a long-term inventory and monitoring effort. By means of different potential sources (field inventory, remote sensing and ecosystem models) one can easily achieve requirements of continuously updated resource data and long-term inventory and monitoring. In order to characterise NPP accurately and understand its relationship with different meteorological parameters the study region should be protected and least disturbed. By considering all these missing links in deciduous forests, the present study was aimed at three national parks (KNP, BNP and MNP) in Madhya Pradesh, Central India with the following research objectives:

1) To study spatial variability in the NPP of tropical deciduous forests of KNP, BNP and MNP using field measurements from 2010 to 2014.

2) To obtain NPP of tropical deciduous forests of KNP, BNP and MNP using satellite data from 2010 to 2014.

3) Validation of satellite derived NPP using field data based NPP.

4) Assessment of relation between measured NPP and meteorological parameters (precipitation and temperature) during the study period, for these forest covers.

The study was conducted in three national parks (Kanha National Park, Bandhavgadh National Park, and Madhav National Park) in Madhya Pradesh (India). The regions have predominantly covered by moist deciduous and dry deciduous forest species. Sub-humid climatic conditions prevail over these regions. Usually, May is the hottest month with a mean daily maximum temperature of about 40°C and January is the coldest month with average daily maximum and minimum temperatures of about 24°C and 7°C, respectively. Total annual rainfall in the regions varies from 895 mm to 1445 mm. About 90 percent of the annual rainfall in the regions is received during the monsoon months (June-September). The regions are found climatologically distinct. Based on species diversity and total area of the forest ten quadrates (0.1ha) in each park were laid out across different forest types in the parks. Many representative trees were marked in the each selected quadrates. Forest invenory work was carried out at every three month duration from 2010 to 2014. Trees standing in the sample plot and having GBH more than 10 cm were numbered and band mark was put at breast height (1.37m). Species wise height and DBH of all standing trees was recorded using electroninc clinometer and vernier callipers. Satellite based NPP was estimated using Carnegie-Ames-Stanford Approach (CASA) Model. Inputs are necessitated to train the models were provided by satellite based measurements and field measurements. Validation of the model estimates was carried out by comparing CASA model estimates with the field based NPP estimates. Influence of regional weather parameters on the inter-annual variation in NPP was studied by comparing the CASA NPP estimates with Agro-meteorological Station (AMS) recorded weather data (rainfall, temperature and radiation).

Analysis of field measurements carried out at total 30 sample plots in KNP, BNP and MNP, highest number of tree species were recorded in KNP (54spp.) followed by BNP (45spp.) and MNP (18spp.), respectively. Of all the species, *Shorea robusta* was found to be dominant in KNP (49.67% of the total tree population) and BNP (20.6%), and *Anogeissus pendula* (Kardhai) in MNP (29.44%). Among all the regions, stand density was maximum in KNP (767 trees ha^{-1}), followed by MNP (506 trees ha^{-1}) and BNP (466 trees ha^{-1}). Tallest trees (ave. height 15.76m) with largest girth (ave. DBH 23.36cm) were observed in KNP and shortest trees (average height 6.28m) with poor girth (ave. DBH 14.70cm) were recorded in MNP. Among all the regions, KNP hold maximum aboveground biomass (AGB) with an average of 332 Mg ha^{-1} followed by BNP (187.06 Mg ha^{-1}) and MNP (56 Mg ha^{-1}). *Shorea robusta* tree species in KNP and BNP and Anogeissus pendula in MNP

contributed more than 50% of overall biomass increment by all the forest types in the regions. Mixed forests had comparatively higher biomass compared to forest dominated by single species. Field measurement based NPP showed the highest at moist deciduous forest in KNP (8.20 Mg ha^{-1} $year^{-1}$), followed by at deciduous forests in BNP (6.69 Mg ha^{-1} $year^{-1}$) and dry decious forests in MNP (3.22 Mg ha^{-1} $year^{-1}$). Due to lack of radiation data from 2011-2014, a temperature based radiation model was developed in this study using 75% of the measured radiation and temperature data for the year 2010-2011. The model explains 87% of the radiation variability in all the regions. Validation of the modelled radiation using 25% of the remaining measured radiation data showed good agreement (R^2=0.85) with an error of 14%. Multidate Landasat TM, ETM+ and MODIS surface reflectance data was acquired for the study period. Atmospheric correction of Landsat images using FLAASH (Fast Line-of-sight Atmospheric Analysis of Hypercubes) module showed significant increase in contrast and greater improvement in image visualization in areas with high aerosol loading, occurring due to local forest management activities like burning of unpalatable grasses etc. Reduction in reflectance values was observed in red band after atmospheric correction. On the otherhand, reflectance values in NIR band increased after the atmospheric correction. Medium spatial resolution satellite data with multi-temporal images acquired at key phenological phases improves forest type classification accuracy at regional scale. In the present context, Landsat derived NDVI of multi-season was used to achieve classification accuracy between 82% (MNP) and 90% (KNP).

CASA simulated NPP was found to be maximum in KNP (8.39 Mg ha^{-1} $year^{-1}$), followed by BNP (7.41 Mg ha^{-1} $year^{-1}$) and MNP (3.7 Mg ha^{-1} $year^{-1}$), showed a gradually decreasing trend from Southeast (KNP) to Northwest (MNP) part of Central India. NPP showed differences among different forest types. It appeared to be maximum in case of moist deciduous forest in KNP and minimum at dry deciduous forest in MNP. Validation of CASA simulated NPP using field measured NPP over KNP, BNP and MNP indicated good agreement with an average error (%RMSE from mean observed NPP) less than 20%, ranging from 9.43% (KNP) to 18% (MNP). The degree of agreement between both the data sets justifies the model's utility for estimating tropical deciduous forest NPP in KNP, BNP and MNP. The association between NPP and major climatic parameters (rainfall, temperature and radiation) indicated strong positive correlation with rainfall (r=0.88) and negative correlation with temperature (r=0.37) and radiation (r=0.37), respectively. High

correlation with rainfall implies that rainfall was a major driving force of NPP variability in the study regions. This strong correlation also suggests that NPP may be the key biophysical parameter for determining rainfall effects on deciduous forest growth in these study regions.

To conclude, it may be emphasized that RS data and RS data driven ecosystem models as technology tool are of paramount importance in the present scenario. Their relevance and use in sustainably managing forests needs no more elaboration. It has been reiterated time and again that in order to ensure environmental sustainability, conservation and restoration have to be regarded as the two quintessential pillars to achieve the same. For the two processes to be effectively executed, the provision of near real time information becomes paramount. Remote sensing is thus, the means to this end. Therefore, it is imperative to suggest that at country level, all state forest departments should get acquainted with these modern, objective, cost effective and time saving techniques of remote sensing in order to attain the goals of environmental sustainability, human and natural resource management.