Growing Stock Estimation in Forest Type Group-V of Haridwar District, Uttarakhand, India, using Geospatial Technology

Poonam[1], Ekta Singh[2], Dharmendra Singh[3]
[1]Forest Research Institute, Dehradun
[2]Forest Survey of India, Dehradun
[3]Indian Institute of Remote Sesning, Dehradun
Email:*dharmbaghel01@gmail.com*

ABSTACT

The present study deals with combined usage of satellite remote sensing data and ground survey inventories to assess growing stock in per ha. and in the strata of forest type group-V. This exercise also yields three crown density classes i.e. more than 70% (VDF), between 70-40% (MDF) and between 40-10% (OF) for each forest sub-type comes under the forest type group-V. As per this estimation, based on IRS LISS-III satellite data of the year 2004, the total volume or growing stock per ha. of forest type group-V of different forest density classes of Haridwar district are 150.20 m^3 for VDF, 95.776 m^3 for MDF and 43.505 m^3 for OF. Result shows that about 1.56% of the total growing stock is contributed by VDF, 53% by MDF, 45.44% by OF. 81% of the total growing stock is stored in forest subtype 5B/C2 (Northern Dry Mixed Deciduous) and 5/1S2 (Khair Sissoo Forest). Pattern of growing stock accumulation is 5B/C2>5/1S2>5B/cC1>5/DS1. Forest subtype 5/DS1 (Dry Deciduous Scrub) is covering lowest area and thus showing lowest growing stock accumulation among all the subtype of the forest type group-V and need immediate conservation measures to be taken.

Keywords: Forest density, Satellite data, 5B/C2 (Northern Dry Mixed Deciduous), 5/1S2 (Khair Sissoo Forest).

Introduction

Forests are the most valuable natural resources because of its economic, environmental, aesthetic and recreational values along with its renewable nature (FAO 1997, Mahto 2001, Moore et al. 2011). Due to ever increasing population and its inexorable needs, these resources are facing extreme pressure (Shaheen et al. 2011). To facilitate sustainable forest resource utilization and its management and to reduce anthropogenic pressure, forest planner requires key information such as growing stock, stand density, stand height etc. (Franklin 2001). Information on status of growing stock of the forest cover in the country is very important to obtain the gap in demand and availability of forest resources to sustain this demand (ISFR 2011, 2012). Growing stock is also, key information required in forest policy formulation, (FSI 2003, Vidal et al. 2008, FAO 2010) however it is not possible to assess the growing stock at a given point in time for a given landscape with classical inventory methods (Mahto 2001). Simultaneously it is not realistic too because of time and budgetary limits. Geospatial technology along with traditional field survey have been extensively applied in the field of forest inventories to estimate the growing stock (Mackrobert & Tamppo 2007, Singh et al. 2012) at landscape level and have been found cost and time effective (Singh & Singh 2013).

Applications of remote sensing and geographic information system (GIS) in forest inventories can be categorised in to three state of art: (1) observation or measurement, meaning using remotely sensed data in place of field observations or measurements; (2) estimation, meaning calculation of traditional inventory areal estimates such as forest area or volume per unit area; and (3) mapping (Mackrobert & Tamppo 2007). Several work have already been done to assess forest parameters such as leaf area index (LAI), Growing Stock, Stand height, biomass etc. using field inventory incorporated remote sensing models (Asner 1998, Rai & Chauhan 1998, Singh et al. 2004, Shvidenko et al. 2007, Chhabraa et al. 2002, Patenaude et al. 2005, Kindermann et al. 2008, Singh et al. 2012, Lausch et al. 2012, FSI 2012, Singh & Singh 2013).

FSI in 1995 attempted growing stock estimation at country level using a methodology which involved use of remote sensing data (satellite imagery as well as aerial photographs) and volume factors based on forest field inventory data (ISFR-2011 2012). Singh et al. (2004) have also used the satellite data for growing stock estimation in part of Doon valley. Singh et al. (2012) and Singh & Singh (2013) have estimated above ground biomass in the forest of Jammu and Kashmir and in Rajpur Hills and Mussoorie hills of Uttarakhand respectively using remote sensing approach. Mackrobert & Tamppo (2007) have reviewed all the aspect of forest parameter retrieval under National Forest

Inventory (NFI) programme in geospatial domain. Most of the studies related to the growing stock estimation have revealed that it varies with crown/forest density and forest type however very few studies are reported regarding growing stock accumulation at forest type group level (Singh et al. 2004, Singh et al., 2012, Singh & Singh 2013). As India itself is much diverse in its forest type with 6 major groups, 16 types, 46 sub-types and 221 ecologically stable formations (Champion & Seth 1968), the distribution of growing stock among them would also be diverse. Knowing its distribution at landscape level, which is possible through geospatial technology, may help in formulating scientific management policies for the forest (Singh & Singh, 2013). Present study highlights the application of satellite remote sensing technology and Global Positioning System (GPS) in quantification of forest growing stock in the forest type group-V (dominant forest type) in the Haridwar district of Uttarakhand, India. Results of this study would be applicable as baseline information for the forest managers and to assess biomass and carbon densities (both these parameters are growing stock dependent) in the subtypes of forest type group-V, as this is first of its kind study have been done with IRS P6 LISS-III satellite data in this area. Simultaneously it will also indicate about most vulnerable forest sub-type (forest sub-type with minimum coverage area and minimum growing stock) among forest type-V and which need immediate conservation.

Forest type group-V (Tropical dry deciduous forests)

Forest type group-V plays a key role in Indian environment as the maximum proportion of the countries forest area is occupied by them (Champion & Seth 1968). These forests (annual rainfall varies between 500mm to 1500mm at country level distribution, about 1100 mm reported at Hardwar area) have been degraded heavily during the past few decades because of increasing population pressure (Mahto 2001, Ashutosh et al. 2010, Web[1]). The effect is felt more as growth of these forests is slow and regeneration is poor. Information with respect to these forests, their type, quality and distribution is of prime need for adopting conservation measures, eco-balance and planning-cum-management aspect. They are distributed from southern portion (south Deccan plateau) of the country to the northern part of it, based on this they are categorised into southern Deccan plateau dry deciduous forest and Northern dry deciduous forest (Web[1]).

The general appearance of the northern tropical dry deciduous forest is very closely similar to that of its southern counterpart, differing most noticeably in the presence of certain conspicuous northern floristic constituents and the absence of some of the characteristic southern species, and in the typically rather different physiographic and soil which also affect the composition and structure to some extent. Variation in physiography, soil and vegetation composition and structure, builds distinctive physiognomy and unique structure in forest patches which make them unique from their surrounding vegetation. Based on these distinctive physiognomy and unique structure, forest type group-V of Haridwar district (northern dry deciduous forest) is categorised into four sub types viz. Dry Plain sal forest (5B/C1b), Dry deciduous scrub (5/DS1), and Northern dry mixed deciduous forest (5B/C2), Khair-sissoo forest (5/1S2) (Champion and Seth, 1968). The peculiar characteristics of these forest sub types (Champion & Seth 1968, Pandey et al. 2008, Ashutosh et al. 2010, ISFR-2011 2012) are listed in the table no. 1.

Materials and Methods

Study Area

Haridwar district, covering an area of about 2360 km², is the southwestern part of Uttarakhand state and is located in between Shiwalik Hills in the North and Northeast and Ganga River in the South within latitude of 29.58 degree north and longitude 78.13 degree east. However, since it is not cradled by the mountains, its weather is also affected by the conditions in other parts of Northern India. Mean height of the study area is 249.7 metres from the mean sea level (Web[2]). Average yearly temperature varies from 16.2˚C to 28.5˚C. Annual rainfall is 2,374 mm.

The flora found in the area is diverse with distinct vegetation zones that include broadleaved deciduous forests, riverine vegetation and grasslands along with picturesque forests of pine trees that lend a unique charm to the environs.

Champion & Seth (1968) and further FSI (2011-2012) have reported following four type of forest subtype in Haridwar district i.e. Dry plains Sal forest (5B/C1b), Northern dry mixed deciduous forest (5B/C2), Dry deciduous scrub (5/DS1) and Khair-sissu forests (5B/1S2) forest. Being a pilgrims place in India it is highly affected by the population pressure (table 1).

Table 1: Subtypes and related characteristics of forest type-V of Haridwar District, Uttarakhand

Subtype	Distribution	Soil Type	Average annual Rainfall	Mean annual Temperature	Associates	Regeneration/ Remarks
Dry Plain sal forest (5B/C1b)	On flat ground, lower end of the bhabar, slightly above the bhabar-tarai	Top Soil Clayey, underlain by gravel or coarse sand	500-1500mm, mostly persist at lower limit	Maximum temperatures higher	*Terminalia tomentosa, Pterocarpus marsupium, Madhuca indica, Diospyros tomentosa, Aegle marmelos* etc.	Practically nil
Dry deciduous scrub (5/DS1)	Throughout the dry deciduous forest zone of India, mostly near thick habitations	Alluvial soil, Thin and gravelly	900-1150mm	24-27˚C	*Acacia catechu, Casearia tomentosa, Buchanania lanzan, Lannea coromandelica, Salmalia malabarica, Holarrhena, Dodonaea, Rabdia, Carissa, Zizypus xyopyrus, Zizyphus numularia, Gardenia turgida, Balanites aegyptiaca* etc.	Poor, Degradation is due to maltreatment mostly over felling, Overgrazing and annual fires.
Northern dry mixed deciduous forest (5B/C2)	Throughout northern India except in the eastern parts	Alluvial soil	Typical rainfall is 900 to 1,150 mm	24-27˚C	*Anogeissus latifolia, Diospyton melanoxylon, Miliusa tomentosa, Mitragyna praviflora, Bridelia retusa, Salmalia malbarica, Holoptelia integrifolia, Terminalia tomentosa, Shorea robusta, Bahuhinia racemosa, Boswellia serrate* etc.	Same as 5/DS1
Khair-sissoo forest (5/1S2)	Along the drainage pattern	Sandy or gravelly alluvium, New deposits, unstable, very porous, hot	500- 1300 mm	24-27˚C	*Dalgerbia sissoo* predominates, *Acacia catechu* etc.	Poor

Data Used

The satellite data from Indian Remote Sensing Sensor (IRS P6) LISS-III satellite data of Oct-Nov 2004, with a spatial resolution of 23.5×23.5 m made available by FSI (for the extraction Forest cover map of Haridwar district under its national Forest Cover Mapping, FCM project) and field data on forest type group-V, Species composition, crown density, DBH, and other field level observation and measurements was used in this study to assess growing stock.

Ancillary data such as topo-sheet of 1:50,000 scale (53K01, 53K02, 53K05, 53J04, 53F16, 53G13, 53G14, & 53G09) have been used for referencing satellite images. Forest type map of Haridwar district were made available by Forest Survey of India (FSI) was taken to couple it with forest density classes. Field Equipment such as Silva Ranger compass , Hega Altimeter, Diameter and linear measuring tapes, Diameter caliper, Nylon rope, Cloth flags, Wooden pegs, GPS (Garmin-72) etc. have been taken to collect the ground information regarding growing stock estimation such as GBH, tree height plot location etc. Images obtained from space based plate form were processes in ERDAS/Imagine version 9.1.

Methodology

In compliance with the earlier mentioned objectives, a suitable Remote Sensing GIS based Methodology was adopted. The entire methodology of the present work have been categorised in the following three stage (a) Pre-field work, (b) Field data collection (c) Post field work. All these stages are elucidated below:

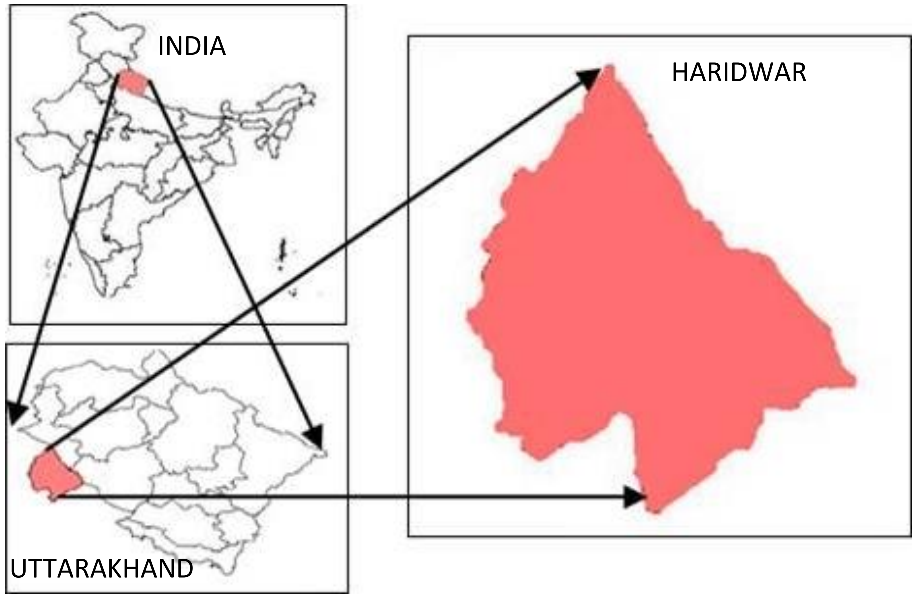

Fig 1: Location of the Study area

Pre-field work: The satellite data worked out in the present study were IRS-P6 LISS-III images with a spatial resolution of 23.5 m. After geometric correction in ERDAS IMAGINE 9.1 software by taking SOI toposheet as reference, the satellite images were mosaicked and Haridwar area was subset. The image was classified through Iterative self-organized data (ISODATA) classification algorithm into 30 odd classes. False colour composite (FCC) image of the study area was visually interpreted for spectral properties of various features like vegetation, water and other non-forest land covers, to classify the 30 pixel classes into various forest cover classes (such as OF, MDF and VDF) as well as water and non-forest classes by assigning a colour code to each of these classes.

The on-screen visual image interpretation involves various image interpretation keys such as colour, Tone, texture, pattern, association and position with inputs from toposheets, ground truth information from earlier work and high spatial resolution Google Earth imagery. Forest density classes were sliced from the vegetation class of classified image, based on the tone and texture of the vegetation cover in the FCC (Dark red tone with coarse texture= VDF, Medium dark red tone with relatively less coarse texture=MDF and Light red tone with smooth or very less coarse texture=OF). Classified image raster attributes were recoded to assign a specific no. to each class was the next step of pre-field work. To remove “salt and pepper effect” from the classified maps “Clump” (connected neighbours=4) and “Eliminate” functions (with a patch of minimum 1 ha. area) were used over the recoded classified image. The output of this step was the preliminary forest cover map which we were planning to integrate with forest type group five after post-field corrections but forest type map (from FSI) of the study area were having various forest type group presents in it. The overall accuracy of the forest cover map was 86.84% and Kappa was 0.8443.

As our interest was in Forest type group Five (Tropical dry deciduous forest which is most dominant and vulnerable to degrade), it has been recoded in such a way that all the forest sub-type of this group found separate code such as one, two, three and four and rest as zero (Figure 2). A subset of preliminary forest cover (Figure 3) equal to the forest type group-V was made for the stratified random sampling strategy preparation.

Field Data Collection: Field sampling strategy was based on the stratified random sampling method, however due to less variation in plot level growing stock (VDF, MDF and OF) only 29 plots were laid. The plots were laid down in such a way that all the plots are equally distributed in different forest density classes based on ratio fraction (percentage of coverage area by different density classes). GPS (Garmin 72) was used for determining positions. Randomly selected inventory points on forest density map with latitude/longitude were generated automatically using ERDAS Imagine software. With the use of GPS, we easily determined the distance and the direction of the selected inventory points on the ground. The randomly selected inventory points (n=29) have been well distributed on the forest density map (5 in VDF, 13 in MDF and 12 in OF). Standard method of laying plot for field inventory work by FSI has been applied for this study. The plot centre reached after covering desired distance and bearing from the reference point represents the centre of the plot of 0.1 ha. (i.e. the point of inter section of two diagonals i.e. NE to SW and NW to SE of the plot). The length of each diagonal measures 44.72 m. After fixing plot centre the

NE at 45^0, SE at 135^0, SW at 225^0, NW at 315^0 corners of the plot have been fixed by measuring 22.36 m. horizontal distance. The dimensions of the plot i.e. all sides have been measured 31.62 m. horizontal distance. Anatomy of the growing stock measurement plot is given in the figure 4. All the plants (GBH>15 cm) within the vicinity of the plot were measured individually and listed in the field form along with their individual heights.

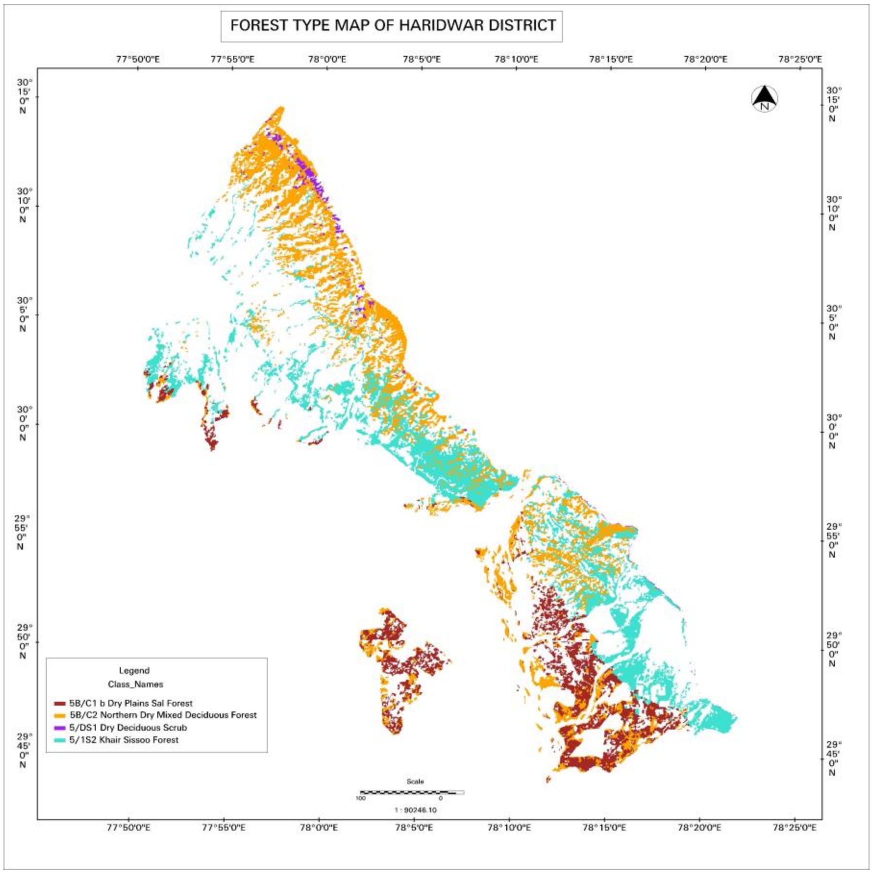

Fig 2: Forest type Map (Group-V) of Haridwar District

Post-field Work: On the basis of Fieldwork, ground truth and available data and knowledge, the finalization of forest cover mapping work was done and further analysis was carried out. Incorporation of more information in the forest density map from ground has made it more accurate. Data collected from the field inventory was analysed in the Microsoft excel 2008. Both the thematic data layers i.e. Forest type (Figure 2 and Forest cover (Figure 3) were subjected to the matrix function of the ERDAS Imagine 9.1 to create a composite layer having distribution of density classes in the forest type group-V. The output of matrix function was forest type density map (Figure 5). A total of 12 combinations (4 forest sub-types×3 forest density classes) have been made and area of each combination was used as multiple factor for the volume estimation under respective combination of particular density class. The mean volume or growing stock from the sampled plot under individual density classes i.e. Mean volume of VDF, MDF and OF, were multiplied by multiple factor of their respective forest type density class.

Computation of volume for each individual tree come inside a sample-plot were carried out using species and site specific volume equations developed by FSI in 1996 (Table 2). In this way the total and per hectare growing stocks for forest type group five in different density classes of the forest cover of the study area have been calculated respectively. The growing stock calculated, is for 0.1 hectare because the Sample plot was laid out in the field of 0.1 ha area. The growing stock per hectare has been computed by up scaling method with the multiple factor of 10 (i.e. by multiplying 10 with the growing stock of 0.1 ha.). The same has been expended for the forest type group five using area as multiple factor.

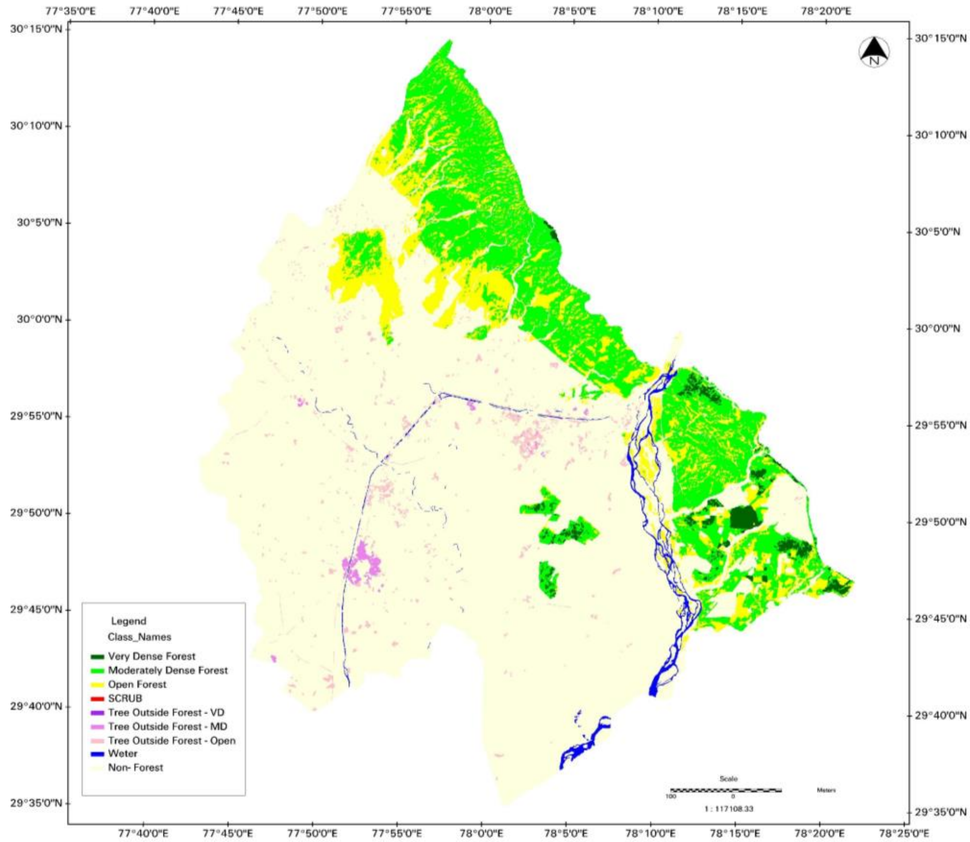

Fig 3: Forest Cover Density map of the Haridwar district, Uttarakhand

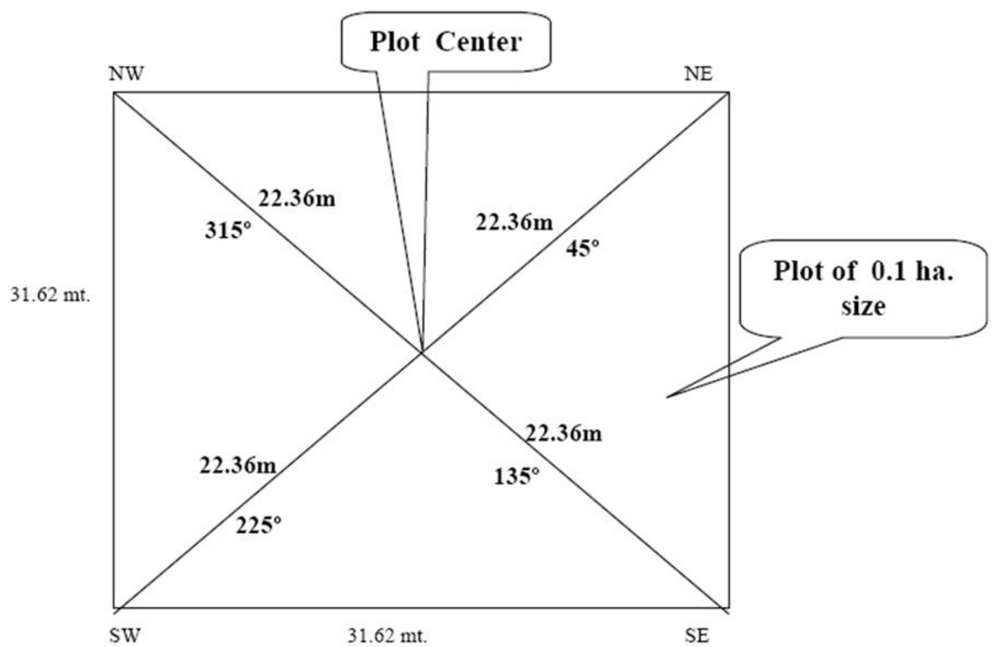

Fig.4. Growing Stock inventory sample plot

Table 2: Species and site specificVolume equations used to calculate volume

Species	Volume Equations
Acacia catechu	$V=0.16609-2.78851D+17.22127D^2-11.60248D^2$
Diospyros species	$V=0.06206-1.43609D+9.778164D^2$
Eucalyptus species	$V=0.02894-0.89284D+8.72416D^2$
Holarrhena antidysenterica	$V=0.17994-2.78776D+14.44961D^2$
Lagerstroemia parviflora	$V=0.10529-1.68829D+10.29573D^2$
Mallotus philippinensis	$V=0.14749-2.87503D+19.61977D^2-19.11630D^2$
Shorea robusta	$\sqrt{V}=0.16306+4.8991D-1.57402\sqrt{D}$
Tectona grandis	$V=0.08847-0.46936D+11.98979D^2+1.970560D^2$

Results and Discussion

Forest Cover Density

The total geographical area of Haridwar district is 2, 36,000 ha. The forest cover (Fig. 3) in the district, based on interpretation of satellite data of Oct-Nov 2004, is 61,900 ha, which is 26.23 % of the distict's geographical area. It includes VDF, MDF, OF, TOF-MDF, TOF-OF, Water and Non-Forest (includes settlement fellow land, forest blanks etc.) classes.

Forest cover having canopy density 70% or more than 70% is classified as VDF. Forest cover having canopy density 40% or more and less than 70% of the per unit ground area have been considered as MDF. OF forest were those forest patches having canopy density 10% or more and less than 40%.

The forest patches situated in the city and those are outside the natural forest areas are termed as TOF. They have been further classified in to MDF and OF-TOF. The areas of TOF classes were added in the respective density classes of natural forest which gave forest cover in terms of forest canopy density classes. The district has 2,600 ha very dense forest, 35,400 ha moderately dense forest and 23,900 ha open forest.

Growing Stock Statistics from Field

Table 3 is showing plot level vegetation parameters. From this table a clear variability can be seen in the plot level diameter. OF is having less diameter (236.39 cm) as compared to the MDF (533.45 cm) which have less diameter than VDF forest (700.76) at plot level. Similar variations are seen in the total volume at plot level. OF, MDF and VDF have 4.35±4 m^3 (Mean± standard deviation), 9.58±6 m^3 and 15.02±6 m^3 respectively. Variation in the volume and diameter at plot level came from no. of trees occurring in the plot. OF, MDF and VDF forest are having average 11±4, 25±6 and 34±11 no. of trees.

Table 3: Per plot mean diameter and volume derived from field inventory points (n=29)

Per plot (0.1 ha) mean Diameter (cm.) and Volume (m^3)			
FTD	Diameter	Volume (Growing Stock)	Average No of Plant
OF	236.39±12.21	4.35±4	11±4
MDF	533.45±12.04	9.58±6	25±6
VDF	700.76±8.70	15.02±6	34±11

The mean parameters for the individual tree given in table no. 4 are representing less variation in the diameter, Basal area and volume irrespective of the forest density. This is the no. of trees per unit area, which create variation in the volume per ha. (Table 3).

Table 4: Mean Parameters of Individual tree from different density classes

Forest Density	Diameter (cm)	Basal Area (m^2)	Volume (m^3)
OF	20.55	0.04	0.37
MDF	21.49	0.04	0.32
VDF	20.79	0.05	0.45

Individuals present in VDF forest having mean diameter 20.97cm for individual tree. Similarly individual tree of MDF forest is having mean diameter 21.49 cm and individual tree of OF 20.55cm. Mean basal area for the individual tree from VDF, MDF and OF is 0.05, 0.04 and 0.04 m^2 respectively. However mean volume is showing little variation. Mean volume for individual tree from VDF is highest (0.45 m^3) followed by OF (0.37 m3) and MDF (0.32 m^3). Average growing stock is estimated 28.9481 cubic meters. The average growing stock/ha in Very dense forest is much higher (150.20 m^3) than the average growing stock/ha in case of moderately dense forest (95.78 m^3) and Open forest (43.50 m^3) at plot level.

Growing Stock of Forest Type Group-V

Total forest cover area under the forest type-V was estimated 28843.05 ha. Combined area of the forest cover under different forest sub-type was highest in the MDF and lowest in VDF. Among the forest sub-type 5B/C2 is covering highest geographical area (12289.69 ha) covered by forest type-V in Haridwar district. Area coverage of the 5/1S2 is second highest (10881.69 ha) area under the forest type-V. Forest sub type 5B/cC1 is covering 4908.75 ha area. Forest sub-type 5/DS1 is covering lowest area (762.92 ha) among all. The areas (ha) under each forest sub-type are given in table no. 5.

Table 5: Area in different density classes of the forest type-V

Forest Type Group (V)/ Forest Cover Density (Area in ha.)	**VDF**	**MDF**	**OF**
5B/C2 Northern Dry Mixed Deciduous	238.54	9115.64	2935.51
5/1S2 Khair Sissoo Forest	494.44	5302.25	5085.00
5B/cC1 Dry Plains Sal Forest	425.37	3048.66	1434.72
5/DS1 Dry Deciduous Scrub	0.00	430.67	332.25
Total	**1158.35**	**17897.21**	**9787.48**

Table 6: Growing Stock or Volume in m^3 of different forest sub type under different canopy density classes.

Based on mean volume of per ha plot from different density classes, the growing stock of each forest sub-type

Forest Type Group (V)	**Volume in m^3 under VDF**	**Volume in m^3 under MDF**	**Volume in m^3 under OF**
5B/C2 Northern Dry Mixed Deciduous	10376.49	873278.31	440913.60
5/1S2 Khair Sissoo Forest	21508.14	507955.55	763767.00
5B/cC1 Dry Plains Sal Forest	18503.60	292061.63	215494.94
5/DS1 Dry Deciduous Scrub	0.00	41258.19	49903.95
Total	**50388.23**	**1714553.68**	**1470079.50**

coming under forest type-V is estimated (table no. 6). Estimates are revealing that almost 53% of total volume (3235021.40 m^3) is accumulated in the MDF followed by OF (45%) and VDF (1.5%). Growing stock was showing following pattern in different forest type: 5B/C2>5/1S2>5B/cC1>5/ DS1. Forest sub-type 5B/C2 is having highest (873278.31 m^3) growing stock in MDF forest cover (table no. 6) followed by in OF (440913.60 ha) and VDF (10376.49 ha). Forest sub-type 5/1S2 (Khair -Sissoo Forest) is accumulating highest growing stock in OF (763767.00 m3) followed by in MDF (507955.55 m3) and VDF (21508.14). Forest sub-type 5B/cC1 (Dry Plains Sal Forest) is having highest growing stock in MDF followed by OF and VDF. 5/DS1 (Dry Deciduous Scrub) is having highest growing stock in OF followed by MDF. There is no growing stock for VDF for 5/DS1. The total growing stock in 5/DS1 is lowest among all the forest sub-type and it covers less area also that is why it need immediate conservation strategies.

Discussion

Information on Growing stock is vital for scientific management of forests. In the past, this information was obtained entirely on the ground by taking a full stock of every forest cover over a certain diameter class. Collection of ground data is not only time-taking and expensive, but it is difficult in inaccessible areas and becomes out-dated at the time of completion of the project.

However, the use of aerial photograph, supplemented by limited ground data was found quite convincing in the assessment of growing stock. The use of aerial photograph can be replaced with recent satellite remote sensing data.

The methodology used in the present study is same as used in initial estimations except that due to use of better quality of satellite data, improved method of interpretation and improved cartographic resolution, growing stock could be estimated in forest cover patches down to 1 ha in extent as against 25 ha limitations in earlier estimations. The present study deals with combined usage of satellite remote sensing data and ground survey inventories. Incorporation of field inventory in remote sensing technology may support observation, measurement, estimation and mapping of forest biophysical, biochemical and other health related parameters (McRoberts & Tomppo 2007, Asner 1998, Hansen & Schjoerring 2003, Singh et al. 2012). Strata obtained from remote sensing data such as forest density map, forest type map, species map etc. may overcome budgetary constraints and deliver précised accuracy (McRoberts & Tomppo 2007). Taking this in view present study utilizes forest cover derived from IRS LISS-III data and forest type from FSI. The results expected to be more accurate as the sampling was done on the stratified map of the Forest density classes (McRoberts & Tomppo 2007).

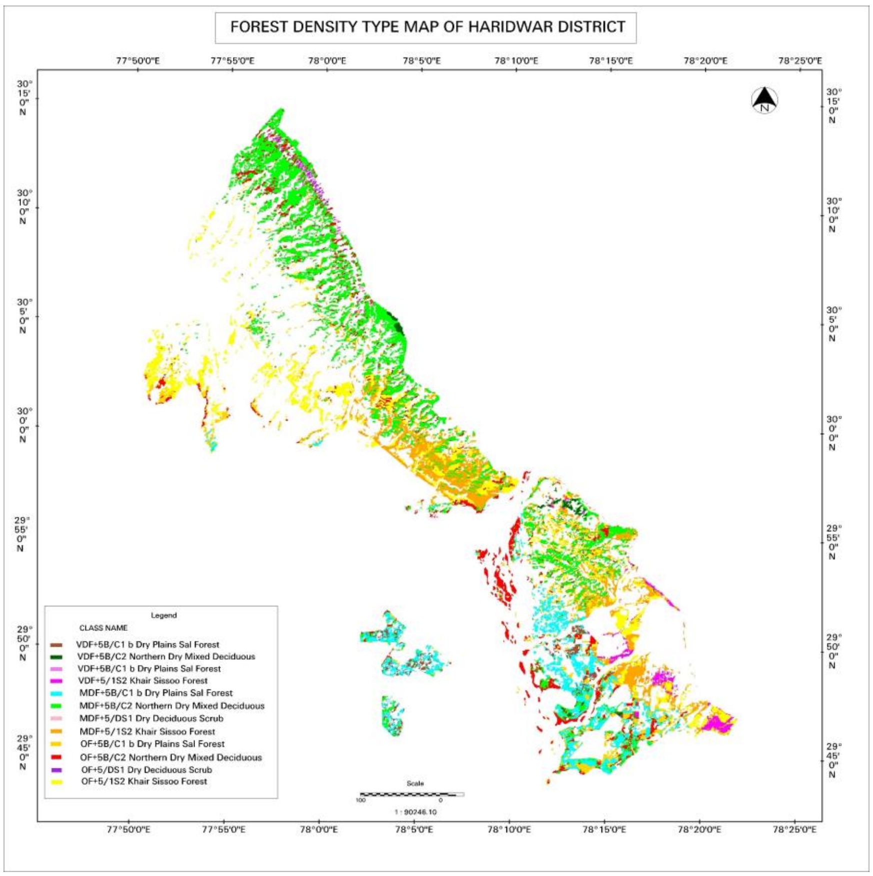

Fig 5: Forest Type Density Map

Total 29 plots were laid on the ground for the growing stock estimation of forest type group-V. Measurement taken from the ground (for trees only) were analysed in Microsoft excel software environment. Matrix of forest density and forest type has given 12 combinations (i.e. 3 forest density classes×4 forest subtype of forest type group-V). Areas of each combination were used as multiple factor to extrapolate the plot level growing stock to the landscape level. This gives growing stock distribution in different forest sub-type density classes.

The no of trees in the open forest are less as compared to the MDF and VDF. Thus the total volume at the plot scale is less in OF. MDF have moderate plot level volume and VDF have highest plot scale volume. However the average volume of the individuals in the forest of Haridwar district is almost similar in all the density classes. This is also little less as compared to the mature forest of the same type which generally have diameter (DBH) greater than 20 cm and thus volume more than 0.49 m^3 obviously. This is showing that the forest type group-V of Haridwar district is having potential to grow and might be preserved for the optimum timber yield. The result outputs of this study are able to deliver valuable information for management purposes. Simultaneously it may also be used as baseline information for the assessment of growing stock, biomass and carbon under different density classes of forest subtype of forest type group-V in near future.

Conclusions

- Remote sensing has enormous potential and it was possible to classify the forest in different types and density classes. Digital image analysis, unsupervised classification and onscreen visual interpretation of the remote sensing data IRS LISS-III (hybrid approach of classification), resulted in forest cover map of the study area including three density classes viz. OF, MDF and VDF along with their coverage area, with reasonable accuracy.
- Creation of database that is of primary requirement for the inventory and growing stock estimation is possible. Thus it can be concluded that the application of modern tools and procedures such as remote sensing technology combined with GIS can be a major input for the quantification of growing stock which is non-destructive and cost-effective (McRoberts & Tomppo 2007).
- Mean diameter, Basal area and growing stock obtained from the sampled individuals i.e. average of diameter, basal area and growing stock from all the individuals of all the plots is less as compared to the mature forest of similar type group. This shows that the forest of Haridwar district comes under the forest type-V is having potential to grow with large prospective to sequester carbon over several decades (Haripriya 2000) and might be preserved for the optimum timber yield. Simultaneously it is obtained that which is the most considerable subtype regarding its conservation. Subtype having less growing stock and spread in less area are considered as unhealthy and needs immediate conservation measures. Present study have shown vulnerability to the dry deciduous scrub (5/DS1) forest sub-type, as it is covering very less percentage (2.65%) of total forest cover and also have low growing stock.
- Further, result output of this study will be used for the management planning of the forest and can be of great help to the forest Departments in the enhancement, updating and diversifying the forestry knowledge at the state and national levels (Khan & Saxena 1997).
- Use of matrix map of forest density and forest type will give more accurate estimation of growing stock as suggested by McRoberts & Tomppo 2007. Nigam (2000) also investigated the application and evaluation aspects of remote sensing and GIS in the biomass estimation and have given similar conclusion.

Acknowledgement

Authors are thankful to the Dr. Anmol Kumar, Director Journal FSI for providing forest type data required under this study. Authors are also thankful to Dr. Sunil Chandra Deputy Director, FSI and Mr. Devi Singh STA, FSI for their valuable suggestions and support during the research work.

References

Ashutosh S, Pandey D, Kaur T & Bajpai RK. 2010. Knowledge-based remote sensing and GIS approach for forest type mapping in Kathua district, Jammu and Kashmir. *Tropical Ecology* 51(1): 21-29.

Asner GP. 1998. Biophysical and Biochemical Sources of Variability in Canopy Reflectance. *Remote Sensing of Environment* 64: 234-253.

Champion HG & Seth SK. 1968. Revised Classification of Forest Types in India, Manager of Publications, Government of India, New delhi.

Chhabraa A, Palriab S & Dadhwala VK. 2002. Growing stock-based forest biomass estimate for India. *Biomass and Bioenergy* 22(3):187-194.

ERDAS Field Guide™, 03 November 2005, Geospatial Imaging, LLC Norcross, Georgia.

FAO. 2010. Developing effective forest policy A guide. Available online on http://www.fao.org/docrep /013/i1679e/i1679e00.pdf. Accessed on date 07-05-2014.

Franklin SE. 2001. Remote Sensing for Sustainable Forest Management. Lewis publisher, 1-409.

FSI. 1996. Forest Survey of India, “Volume Equations for Forest of India, Nepal and Bhutan”, 1996.

Hansen PM & Schjoerring JK. 2003. Reflectance measurement of canopy biomass and nitrogen status in wheat crops using normalized difference vegetation indices and partial least squares regression. *Remote Sensing of Environment* 86:542-553.

Haripriya GS. 2000. Estimates of biomass in Indian forests. Biomass and Bioenergy 19(4): 245‑258.

Indian State of Forest Report 2011 (ISFR-2011), 2012. Forest survey of India, 1-286.

Kindermann GE, McCallum I, Fritz S & Obersteiner M. 2008. A global forest growing stock, biomass and carbon map based on FAO statistics. *Silva Fennica* 42(3): 387–396.

Lausch A, Pause M, Merbach I, Zacharias S, Doctor D, Volk M & Seppelt R. 2012. A new multiscale approach for monitoring vegetation using remote sensing-based indicators in laboratory, field, and landscape. *Environmental Monitoring and Assessment* 185(2):1215-35.

Lindberg K, Furze B, Staff M & Black R. 1997. Ecotourism and other services derived from forests in the Asia-Pacific region: outlook to 2010, FAO, 1-79 available on http://www.fao.org/docrep/w7714e/w7714e05.pdf, accessed on 02/07/2014.

Mahto B. 2001. Paper presented at the 22nd Asian conference on remote sensing, 5-9 November 2001, Singapore. Copyright (c) 2001 Center for remote imaging, sensing and processing (CRISP), National Universitynof Singapore; Singapore Institute of Surveyores and Valuers (SISV); Asian Association on Remote Sensing (AARS).

McRoberts RE & Tomppo EO. 2007. Remote sensing support for national forest inventories. *Remote Sensing of Environment* 110 (4): 412–419.

Moore R, Williams T, Rodriguez E & Cymmerman JH. 2011. Quantifying the value of non-timber ecosystem services from Georgia's private forests. Final Report submitted to the Georgia Forestry Foundation, 2-44.

Pandey R, Mall TP & Singh RK. 2008. Forest types of Katarniaghat Wildlife Sanctuary- a biogeographic classification. *Environment Conservation Journal* 9(3): 83-87.

Patenaude G, Milne R & Dawson TP. 2005. Synthesis of remote sensing approaches for forest carbon estimation: reporting to the Kyoto Protocol. *Environmental Science & Policy* 8(2): 161‑178.

Rai SN & Chauhan KVS. 1998. Distribution and Growing Stock of Bamboos in India. *Indian Forester* 124(2):89-98.

Saxena A, Dasgupta S, Srivastava P & Rawat JK. 2009. Estimation of growing stock of India's Forest & Tree cover- A Remote sensing and GIS based approach. XIII world forestry congress, Buenos Aires, Argentina, 18-23 October, 2009, 1-6.

Shaheen H, Qureshi AR, Ullah Z & Ahmad T. 2011. Anthropogenic pressure on the western himalayan moist temperate forests of bagh, azad jammu & Kashmir. *Pakistan Journal of Botany* 43(1): 695-703.

Shvidenko A, Schepaschenko D, Nilsson S & Bouloui Y. 2007. Semi-empirical models for assessing biological productivity of northern Eurasian forests. *Ecological Modelling* 204(1–2): 163–179.

Singh S, Patil P, Dadhwal VK, Banday JR & Pant DN. 2012. Assessment of above ground phytomass in temperate forests of Kashmir Vally, J&K, India. *International journal of Ecology and Environmental Science* 38 (2-3):47-58.

Singh D & Singh S. 2013. Hyperspectral Data Application for Above Ground Biomass Estimation in Doon Valley, Uttarakhand. In: *Proceedings*: ISG-ISRS National Symposium-2013 Dec. 4-6, 2013. Andhra University, Visakhapatnam 530003.

Singh IJ, Das KK, Pant DN & Thee N. 2004. Quantification of Forest stock using remote sensing and GIS. *Journal of the Indian Society of Remote Sensing* 32(1):113-118.

The manual of instructions for Forest inventory 2002, Approved by Director, F.S.I. vide No. 27-106/2002, dated the 13th September, 2002, Forest survey of India, Dehradun.

Vidal C, Lanz A, Tomppo E, Schadauer K, Gschwantner T, di Cosmo L & Robert N. 2008. Establishing forest inventory reference definitions for forest and growing stock: a study towards common reporting. *Silva Fennica* 42(2): 247–266.

Websites:

Web[1]: http://www.indianetzone.com/39/indian_dry_deciduous_forests.htm.

Web[2]: http://haridwar.nic.in/pages/display/86-about-district.