CHAPTER 8
SUMMARY

The present study entitled "Biophysical spectral response modeling of forest biomass and productivity using Indian Remote Sensing Satellite data" was conducted in Doon Valley of Dehradun district in Uttarakhand lying between longitudes 77° 35' E to 78° 20' E and latitudes 29° 57' N to 30° 33' N covering an area of about 1825 Km². The terrain of the area is irregular and undulating. The elevation in the study area varies from 340 to 2770 metres above mean sea level (MSL). The summer temperature varies from 38.5°C to 16.7°C and in winters it ranges from 23.6°C to 5.4°C. Precipitation varies from 175cm to 228.6cm per annum. The slope ranges from moderate to little bit steep towards the streamlines. The climate is relatively moist tropical. The forests types are mainly North Indian tropical moist Sal forest, North Indian tropical dry deciduous forest, khair and sissoo dominated riverine forest, scrub and degraded forests.

The Indian Remote Sensing Satellite (IRS – P6), Advanced Wide Field Sensor (AWiFS) cloud free data acquired 17th December 2004 was used for the digital classification of Land use and vegetation. Advanced Wide Field Sensor (AWiFS) is unique as it provides wide swath, 10 bit radiometric resolution, 4 bands multi-spectral at a spatial resolution of 56m
with short revisit period. The study indicated that the AWiFS data due to its higher radiometric resolution incorporates much higher information contents than existing remote sensing data types. The band 4 (SWIR) band has shown its potential for better discrimination of vegetation classes. 13 land use classes were identified. Separability analyses were done between class pairs. The transformed divergence shows poor separability between Sal coppice and Sal mixed when all the four bands were used for classification. Also there is a mixing between Sal (old growth) and Sal mixed. When three bands were used for classification (Bands 2, 3, 4), the best average separability obtained was 1961.68, however there is a mixing between agriculture and fallow land.

Major five forest types (Sal (old growth), Sal coppice, Sal mixed, Oak, Pine and Acacia) have been identified. Forests are found spreading over 82522.59 ha area (45.19% of total geographical area). Non-forest includes the scrub, agriculture, fallow, tea garden, and plantation in addition with riverbed, water body and settlements. 54.8 % of the total geographical area is accounted for non-forest area. In the total forest area, Sal mixed forests were the most dominated forest of the area, occupying 51.40 % of the total forested land and 23.23 % of the total geographic area followed by Sal coppice and Sal (old growth) forests. Within the various forest type classes, four crown cover classes (< 20 %, 21 – 40 %, 41 – 70 %, > 70 %) were recorded, out of which maximum area is occupied by 41 – 70 % crown cover class (56.24 %) followed by 21 – 40
% crown cover class and > 70 % crown cover class (9.21 %). The crown class < 20 % occupies least forested area (7.09 %). The study area has altitudinal variation of 300 m to 2300 m. Out of these, Sal species (Shorea robusta) forests were confined to lower elevation zones, i.e., up to 1200 meters of elevation. Pinus roxburghii forest has shown dominance up to an altitude up to 1800 meters. Oak forests are found in the elevation greater than 1500 meters.

The variation of daily solar insolation under different aspects was studied. In the months of April, May, June and July receive the most radiation and the radiation is fairly evenly spread all over aspects. South facing slopes receive the highest radiation through out the year, though the radiation during winter months of January, February, October, November and December is only about half of that received during summer months of April, May, June, and July. Directional aspect plays very important role in the development of vegetation, particularly, in higher altitudes as the southern aspect is exposed to more insolation. The insolation on southern aspect is about 1.5 to 2 times higher than that of northern aspect. Western aspects receive more insolation than eastern aspects. The difference in the temperature on the different aspects of the hills is the result of differential insolation. The southern aspect is the warmest and northern aspect is the coolest. In the Himalayas, the effect of aspect is very pronounced, particularly, on high altitudes.
In the present study, the total above ground biomass was estimated through crown cover based approach and spectral model approach. In the crown cover based approach, the total above ground biomass in the entire study area is 1781.9 x 104 tons. Among different forest types, maximum above ground forest biomass (1005.77 x 104 tons) is found in Sal mixed forests followed by Sal (old growth) forests (339.6 x 104 tons) and Sal coppice forests (304.9 x 104 tons). Oak forest has a total above ground biomass of 56.8 x 104 tons. The total above ground biomass of Pine forest is comparatively less in the study area and is found to be 28 x 104 tons. The total above ground biomass occupied by Acacia forest is 46.8 x 104 tons. The mean total above ground biomass ranges from 43.65 t ha\(^{-1}\) (Sal coppice with < 20 % crown cover) to 371 t ha\(^{-1}\) (oak forests with > 70 % crown cover). In the Sal forests, the highest mean biomass is found in > 70 % crown cover such as Sal (old growth) has 312.64 t ha\(^{-1}\), Sal coppice has 309.93 t ha\(^{-1}\) and Sal mixed forests have 332.03 t ha\(^{-1}\). Oak forests have shown the highest mean biomass in all the crown cover classes such as 158.27 t ha\(^{-1}\) in < 20 %, 208.11 t ha\(^{-1}\) in 20 – 40 %, 289.59 t ha\(^{-1}\) in 40 – 70 % and 371.13 t ha\(^{-1}\) in > 70 % crown cover classes. Pine forests have shown less mean biomass such as 70.52 t ha\(^{-1}\) in < 20 % crown cover class, 113.23 t ha\(^{-1}\) in 20 – 40 % crown cover class and 151.17 t ha\(^{-1}\) in 40 – 70 % crown cover class. In Acacia forests, the mean biomass is 182 t ha\(^{-1}\). The biomass density of Sal mixed forests is 237.12 t ha\(^{-1}\), which is higher than newly growth Sal forests. Similarly
Oak forests of Doon valley have greater biomass density, 276.82 t ha\(^{-1}\) than other forest types. Chir pine forest has shown less biomass density, 98.68 t ha\(^{-1}\).

A spectral relationship was established between the total above ground biomass estimated from the field and the spectral values from all the four bands of IRS-P6 AWiFS data. The spectral relationship has shown high to medium correlation. The biomass was mapped in to discrete classes of 80 t ha\(^{-1}\) intervals such as < 80, 80 –160, 161-240, 241-320 and > 320 t ha\(^{-1}\). Using this spectral model approach, the Sal mixed forest has shown a maximum of total above ground biomass of 1011.3 x 10\(^4\) tons followed by Sal (old growth) forest (336.3 x 10\(^4\) tons) and Sal coppice forest (305 x 10\(^4\) tons). Oak forest has shown a total above ground biomass of 56.5 x 10\(^4\) tons and Pine forest has shown 28.4 x 10\(^4\) tons. Incase of biomass density, Oak forest has shown a maximum biomass density of 275.54 t ha\(^{-1}\) followed by Sal mixed forest (238 t ha\(^{-1}\)) and Sal (old growth) forest (232.12 t ha\(^{-1}\)). Sal coppice has shown a biomass density of 168.15 t ha\(^{-1}\) and Pine forest has a biomass density of 99.82 t ha\(^{-1}\). Acacia forest has shown a biomass density of 182 t ha\(^{-1}\).

The study has been validated by comparing the total above ground biomass values from the spectral model approach and those from the crown cover based approaches. Both the data sets exhibited a close agreement with \(R^2\) value 0.9365.
The relationship between the biomass allocation in different tree components such as bole, branch, twigs and foliage and mean annual solar radiation in forest type wise is presented in the figures 5.4 to 7.4. In the oak forests, except for component foliage, biomass allocation in bole, branch and twigs showed good relationships with mean annual solar radiation. The $R^2$ values were found to be 0.94, 0.94, and 0.93 respectively. For foliage, the $R^2$ was found to be 0.42. However, in the case of bole, the biomass allocation decreases with increase of mean annual solar radiation and in the case of branch and twigs, biomass allocation increases with increase in mean annual solar radiation.

In this study, two approaches were attempted for regional estimation of NPP viz., crown cover based approach and Spectral model approach. In the crown cover approach, a relationship was developed between crown cover of each forest type and the Net Primary Productivity obtained from reference sites and the respective crown cover values were replaced with the Net Primary Productivity values obtained from the above relationship. Among different forest types, the mean NPP ranged between 4 t ha$^{-1}$ yr$^{-1}$ (Sal coppice forest < 20 % crown cover) to 17.3 t ha$^{-1}$ yr$^{-1}$ (Sal mixed forest > 70 % crown cover). The total above ground Net Primary Productivity was maximum in Sal mixed forest (43.2 x 10$^4$ t yr$^{-1}$) followed by Sal coppice forest (19.1 x 10$^4$ t yr$^{-1}$). Acacia forest exhibited a total Net Primary Productivity of 1.3 x 10$^4$ t yr$^{-1}$. Sal (Old growth) forest has shown a maximum average Net Primary Productivity of 12.1 t ha$^{-1}$ yr$^{-1}$ followed by
Oak (10.9 t ha$^{-1}$ yr$^{-1}$) and Sal coppice forest (10.5 t ha$^{-1}$ yr$^{-1}$) and Sal mixed forest (10.2 t ha$^{-1}$ yr$^{-1}$). Pine forest has shown an average Net Primary Productivity of 6.8 t ha$^{-1}$ yr$^{-1}$. In the spectral model approach, a spectral relationship was established between field measured NPP of the entire Doon valley with spectral values of the four bands of IRS-P6 AWiFS data. The output NPP map were generated with 5 classes ( < 2 t ha$^{-1}$ yr$^{-1}$, 2-5 t ha$^{-1}$ yr$^{-1}$, 5-10 t ha$^{-1}$ yr$^{-1}$, 10-15 t ha$^{-1}$ yr$^{-1}$ and > 15 t ha$^{-1}$ yr$^{-1}$). The spectral model based estimate indicated a maximum total above ground Net Primary Productivity for Sal mixed forest (42.8 x 10$^{4}$ t yr$^{-1}$) followed by Sal coppice forest (19.2 x 10$^{4}$ t yr$^{-1}$). Sal (old growth) forests have shown a total Net Primary Productivity of 17.9 x 10$^{4}$ t yr$^{-1}$. Oak and Pine has a total above ground Net Primary Productivity of 2.2 x 10$^{4}$ t yr$^{-1}$ and 1.8 x 10$^{4}$ t yr$^{-1}$ respectively. The mean Net Primary Productivity for different forest types indicated that Sal (old growth) has shown a maximum average Net Primary Productivity 12.4 t ha$^{-1}$ yr$^{-1}$ followed by Oak forest (10.80 t ha$^{-1}$ yr$^{-1}$). The Sal coppice has shown an average Net Primary Productivity of 10.6 t ha$^{-1}$ yr$^{-1}$ and Sal mixed has shown 10.1 t ha$^{-1}$ yr$^{-1}$. Pine forest has shown an average Net Primary Productivity of 6.5 t ha$^{-1}$ yr$^{-1}$.

The accuracy has been estimated by comparing the NPP values of crown cover based approach and spectral model approach. A relationship has been established by plotting the NPP values of 15 reference sites estimated through crown cover based approach against those estimated
through spectral model. The relation has shown 98.32% correspondence, which gives confidence to the present study.

For a total of 25 sites, the total above ground biomass computed in the present study was related to the independent estimate of productivity. The Sal forest (Old growth) exhibited a significant highly correlated relationship between biomass and productivity. Productivity appears to increase with increase in biomass up to about 320 t ha\(^{-1}\) where as after this biomass level, a decreasing trend of productivity was observed. On contrary, Sal copice forest exhibited ever increasing trend of productivity. In case of Sal mix forest, there is a slow increase in productivity up to the biomass level of about 210 t ha\(^{-1}\). A biomass range of about 200 to 350 t ha\(^{-1}\) appears to have a high biomass to productivity ratio. The productivity shows a decreasing trend after 350 t ha\(^{-1}\) of the biomass. Pine forests exhibited a sharp increase in productivity with increase in biomass up to a total above ground biomass of 150 t ha\(^{-1}\). Oak forest exhibited an increasing trend of productivity with increase in biomass.

The spectral model approach used in this present study for the modeling of total above ground biomass and Net Primary Productivity is expected to play a major role in global biomass mapping and estimation.