CHANGE IN FOREST VOLUME AND TOTAL ABOVE GROUND BIOMASS: A REVISIT STUDY AT ANNAPURNA CONSERVATION AREA, NEPAL

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Paresh Pokharel

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Abstract

Periodic assessment of forest resources is vital as forest plays regulatory role in maintaining environmental balance and provides wide range of ecosystem services. In this context, a study was carried in Mardi watershed inside Annapurna conservation area, Nepal. Current status of stem volume (over bark) and total above ground biomass, and change in volume and biomass in 13 years (1999-2012) were assessed by measuring diameter of the trees ($\geq$ 10 cm diameter at breast height) and tree height at 40 sampling locations in three forest types, namely mixed hardwood forest (MHF), oak forest (OF), and high mountain mixed forest (HMMF) using stratified random sampling. Altitude, accessibility, aspect, and slope angle were also recorded in each plot to assess the variability. Total of 48 tree species were encountered. A significant variation in stem volume and total above ground biomass was found between and among forest types. OF had highest stem volume and biomass (755.9 ± 53.2 m^3ha^{-1}, 1166.2 ± 113 tons ha^{-1}) followed by HMMF (557.5±31.1 m^3ha^{-1}, 766.4± 53.8 tons ha^{-1}), and MHF (282.5 ± 32.2 m^3ha^{-1}, 302.5 ± 32.1 tons ha^{-1}). Tree density was however higher in HMMF (1260 stems ha^{-1}) than OF (1130 stems ha^{-1}), and MHF (805 stems ha^{-1}). Difference in wood density, stem density, and size of the trees between the forest types was the principal reason for such variation. The regression analysis showed 89 % of variability in total aboveground biomass explained by altitude, accessibility, and slope in OF and 80% of variability in HMMF. The estimated stem volume and total above ground biomass were in general higher than figures reported in other parts of the country and elsewhere. Comparison of present findings with the estimate of 1999 however, did not show significant changes in stem volume and biomass densities among forest types. Nevertheless, the present estimate revealed minor growth in stem volume, in MHF (from 232.6 to 282.5 m^3ha^{-1}), OF (from 711 to 755.9 m^3 ha^{-1}), and HMMF (from 512.7 to 557.5 m^3 ha^{-1}) since 1999. Similarly, total above ground biomass was also increased during this period in MHF (from 270.8 to 302.5 tons ha^{-1}), OF (from 1026.7 to 1166.2 tons ha^{-1}), and HMMF (from 675.1 to 766.4 tons ha^{-1}). Among the variable classes studied, a significant change in volume and biomass in forests at higher altitude and low accessibility was observed during 13 years. The higher volume and biomass in Mardi watershed and changes since 1999 may be mainly attributed to cumulative effect of efficient conservation and management efforts by community involved and favorable environment for productive forest.

(**Key words: Stem volume, biomass, revisit study, Conservation area, biomass change**)

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1. Introduction

Forests are the natural warehouse of biomass and carbon, its vegetative biomass represents largest terrestrial carbon sink (Dixon et al. 1994). Therefore, the existence of forest system has two equally important dimensions: it plays regulatory role in maintaining environment, and serves as the provider of wide range of tangible and intangible benefits to its resources based livelihoods. However, population growth and subsequent pressure on subsistence has geared up deforestation and forest degradation throughout the world, the instance is more rapid and severe in developing countries (Hosonuma et al. 2012). As a result, overall supply of ecosystem services provided by forests has been impaired (Foley et al. 2007) threatening substantial forest dependent population. Periodic monitoring of forest resources is thus crucial, since efficient conservation and management of forest requires updated forest details. In this context, measurement of forest volume and biomass can be an excellent indicator of present state of forest and scale of forest system change (Brown et al. 1999; Tan et al. 2007; Wang 2006). Reliable and updated information about forest resources not only provides latest status of forest resources but also serves as a basis for making best possible conservation and management policies. Sustainably managed forests ensure multiple environmental and socio-economic benefits and hence for developing country like Nepal where majority of people are agrarian, it is unavoidable (Adhikari et al. 2004; Bajracharya 1983; Thapa 1996).

The depletion of forest resources in Nepal started rapidly during 1950’s after a series of political changes and subsequent enforcement of forest management policies (Mahat et al. 1986). Since then, large patches of forests have been cleared out for various human needs until 1970’s. In order to control widely spread problem of forest degradation and deforestation, government of Nepal promulgated a legislation to integrate forest dependent local communities as the principal actor in forest conservation and management since 1978. The introduction of community managed forestry was found successful not only in increasing forest cover (Gautam et al. 2002; Nagendra 2007), but also in improving livelihood of rural populace (Pokharel et al. 2007). The latest figure accounts that more than 25% of the total forest in Nepal has now been managed by communities (DOF 2012). Even though, Nepal has substantial experience in forest management and conservation among its counterparts, there is paucity of updated forest information, more specifically the data pertaining to temporal assessment of forest resources are inadequate. The national forest inventory has not been updated so far. The latest national forest inventory is seventeen years old and since then several policies and priorities towards forest resource management have been put forward. Among available forests evaluation studies, majority are focused on structure of forests and carbon stock (Baral, S. K. et al. 2010; Oli & Shrestha 2009). Studies on temporal forest assessment are mainly carried out on forest cover change (Gautam et al. 2004a; Nagendra et al. 2008; Panta et al. 2008). Temporal assessments of forest attributes; volume and biomass, in particular, are very scarce (Beek et al. 2001; Jefferson 1993; Karky & Skutsch 2010). In these scenarios, the need to conduct timely forest resource assessment especially at local level has become more pronounced as Nepal is a signatory of United Nations Framework Convention on Climate Change (UNFCCC) mechanisms. Moreover, Nepal has good set-up of protected areas as National Parks, Conservation Areas, Wildlife Reserves, and Hunting Reserves and represents 15 percent of country's area (Agrawal & Ostrom 2001). However, these areas have not been included in forest resource assessments until now with an understanding that these forests are beyond accessibility and need not to be assessed. The assumption is not correct because unlike other protected areas the conservation areas have been managed by local communities.

On the aforementioned ground, the present study was carried out at watershed level in the largest community managed conservation area in Nepal. The main objective of this study was to assess the present state of forest volume and biomass and the changes occurred in terms of forest volume and biomass between two measurement periods. Consequently, this study will try to answer the following research questions:

- What is the current status of forest volume and biomass?
- Have there been significant changes in volume and biomass among the forest types since 1999?
- Have there been any changes in volume and biomass in forests in relation to altitude, accessibility, slope angle, and aspect since 1999?

2. Methods

2.1 Study area

This study was carried out at Mardi watershed (83º 50′ E to 83º 56′ E and 28º 19′ N to 28º 29′ N), a mid hill landscape in western Nepal (Figure 1) which ranges about 900-5587 m above sea level. The study area is a part of Annapurna Conservation Area (ACA) and is located about 15 km North West of Pokhara, a regional head quarter of western development region. The total area of the watershed is 145 square km (Awasthi et al. 2002). However, this study encompasses only 72.2 square kilometer on the lower and southern half of the Mardi watershed. Meteorologically, this region receives higher precipitation in Nepal (MNR/MENRIS & ICIMOD 2008), exceeding 4000 mm per annum which is mainly monsoonal. The watershed has warm and humid subtropical to cool and dry alpine climate with increasing elevation from valley floor to mountain peaks. The mean annual temperature in the valley and the ridges are 26 ºC and 16 ºC respectively (Awasthi et al. 2002).

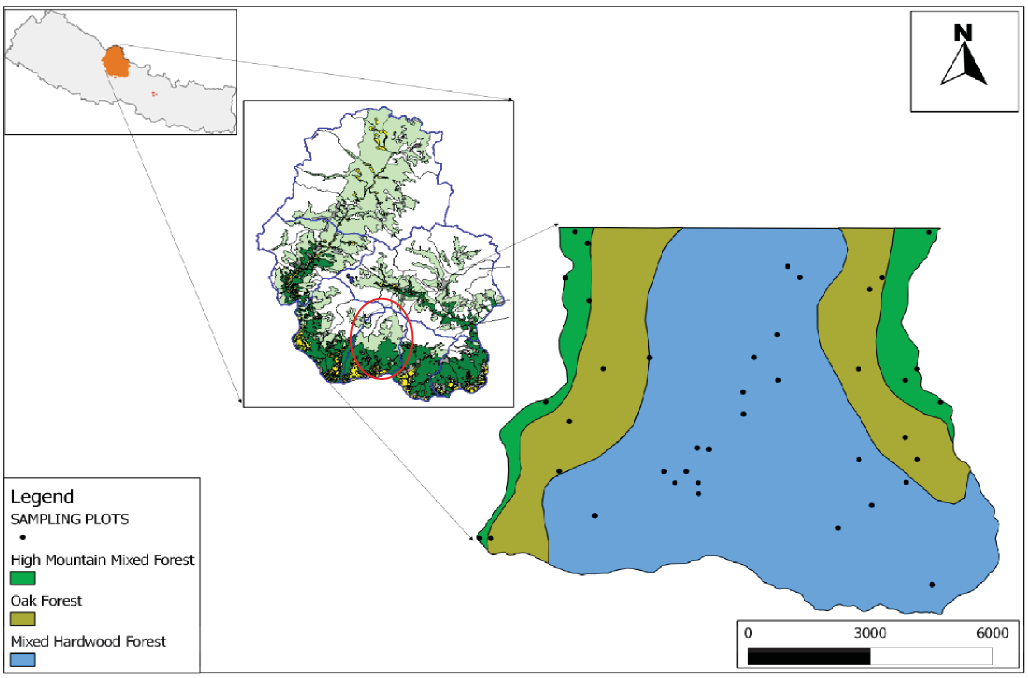

Figure 1 Location of study area and sampling points

The dominant land cover type is forest (58%) followed by cultivated land (22%), the remaining 16% covers others as reported by Awasthi et al. (2002). The major forest types are Mixed Hardwood Forest, Oak Forest, and High Mountain Mixed Forest (abbreviated as MHF, OF, and HMMF here after) as classified by Stainton (1972). *Schima-Castanopsis* are dominant trees in MHF but *Alnus nepalensis* is major species in all community plantation sites. *Shorea robusta*, is also present in the valley floor. Species of *Quercus* dominates OF, whereas *Rhododendron* is major species in HMMF. *Daphiniphyllum* is also common and is found frequently between 1500-2500 m.

The watershed encompasses five village development committees: Dhital, Dhampus, Lahachowk, Ribhan, and Lwang Ghalel. Out of these, Dhital VDC is not included in ACA. VDCs are ground level autonomous political units in Nepal. Conservation area management regulations 1997 is a legislative act under which Conservation Area Management Committees (CAMC) have been established in each of this VDCs. CAMC is responsible for management, utilization and protection of all natural resources within the premises of ACA.

Mardi watershed has been used as study site for a number of studies, some are on land use change (Awasthi et al. 2002); soil organic carbon and forest degradation (Sitaula et al. 2005); land use and forest degradation (Sankhayan et al. 2003), and natural resources degradation (Thapa & Weber 1992).

2.2 Annapurna conservation area and Annapurna Conservation Area Program

Annapurna Conservation Area (ACA) is the pioneer and largest protected area of its type in Nepal with land mass of 7629 km^2. ACA is globally known trekking trail and biodiversity hotspot due to rich natural and cultural heritage. About 120000 people from a medley of eleven ethnic communities live here. The area has diverse topography, within a short span, ranging from ~1000m to 8091m with some of the world's highest peaks in Annapurna mountain range (Annapurna I – 8091 m, Annapurna II - 7,937 m, Annapurna III - 7555 m, and Machhapuchhre - 6993 m). The region has two distinct climatic regions; area south to Annapurna mountain range is the wettest part in the country with annual rainfall exceeding 3000 mm where as the northern part is relatively dry with annual rainfall <500 mm (Bhuju et al. 2007). Due to higher rainfall, southern area of ACA is flourished with dense forests. In this part of ACA substantial human settlement exists. The present study area is also located in this fringe of ACA.

ACA is IUCN (International Union for Conservation of Nature) category VI protected area which follows principles of ecosystems and habitats conservation with traditional natural resource management. Hence, locals residing inside ACA are allowed to continue their traditional land use practice. At the same time, they are the principal actors in the conservation and management of their habitat in its entirety. ACA has been managed by National Trust for Nature Conservation (NTNC), a nongovernmental organization, since its inception in 1986. With the increased tourism after 1970's, this region had experienced rapid environmental degradation. In order to protect environment and sustainability of Annapurna region, Annapurna Conservation Area Program (ACAP) was established in 1986 and was put under NTNC. ACAP was established with three objectives: natural resource conservation, socio-economical development, and sustainable management of tourism (Gurung 2003). Since then, ACAP has been working with local communities through conservation area management committees (CAMCs) formed in each village development committee (VDCs), towards natural resource conservation and sustainable development of the entire ACA.

In order to achieve its goal, ACAP has categorized the total area of ACA into five land use zones. They are - wilderness zone, protected forest zone, intensive use zone, special management zone, and anthropological and biotic zone. The wilderness zone is completely protected highland areas. Protected forest zone is located far away from human settlements at higher altitudes. Intensive use zone is area where substantial human settlements reside, and is under high pressure. This area has been given top conservation priority. Special management zone is the section under special conservation, with priority to recover from past anthropogenic effects. Anthropological and biotic zone is the zone which still has traditional life style and resource management practices (Gurung 2003).

Depending upon the conservation and management needs in these zones, ACAP has implemented variety of activities within the framework of integrated conservation and development programs. The major of which are, natural resource conservation, introduction of alternative energy to reduce pressure on forest resources, conservation awareness programs, technical support to agro-forestry, sustainable tourism, infrastructure development, women empowerment, and conservation of cultural heritage. Under natural resource conservation program, ACAP has helped CAMCs in making management operational plans in all VDCs. The operational plan has categorized the area of VDCs into different land use zones as mentioned above. On the basis of its potentiality, and degree of conservation needs, the access to collect resources from particular forest or land use zones is restricted (CAMC/ACAP 2010). ACAP has been conducting several plantations on previously deforested and degraded areas as well as on private lands. ACAP has also established nursery of tree seedlings and its free distribution. There has also been formation of conservation groups for wildlife. In order to reduce pressure on available forest resources, ACAP has introduced fuel wood efficient improved stove, back boiler system for water heating, solar energy, hydroelectricity, and also established kerosene depots and liquid petroleum gas in collaboration with communities. To increase awareness about resource conservation, ACAP has also been conducting conservation awareness program in schools, study tours, and adult literacy programs. ACAP provides technical support for poultry farming and cash crops farming like vegetables and fruits. Tea gardens have been established in certain parts of ACA, particularly in Lwang, where a tea processing factory has also been installed. In case of managing sustainable tourism, ACAP has been instrumental in giving training to local people, entrepreneurs about establishment of home stays and lodges, its management, encourage them to opt for alternative energy sources rather than forest resources, and assisted in waste management. Besides these, ACAP has also facilitated construction and improvement of several physical infrastructures within ACA. Improvement of trekking trails, construction of suspension bridges, health post buildings, drinking water supply systems, and also support schools buildings construction. Women empowerment has also been a major focus in ACAP because inclusion of women group in several conservation and development programs in other part of Nepal has shown very promising results. In this regard, to increase their participation, ACAP has started day care centers, assisted in reproductive health, provided capacity building trainings, conducted informal education, and also started saving and credit group cooperatives by forming mothers groups in all VDCs. ACAP has also been helping in conservation of cultural heritage by preserving cultural assets, beliefs, practices, and rituals and also by construction and renovation of religious monuments (ACAP 2002).

In fulfilling its objectives, ACAP receives financial support from government, foreign aids, and its own resources. ACAP has been given a right to collect certain amount of entry fee from visitors. In addition to this, ACAP also collects the revenue from the locals as a charge against their use of forest resources like wood harvesting for house hold purposes. The collected money is provided back to community development and conservation tasks through CAMCs.

2.3 Site selection

A total of 40 sampling quadrats of 10m × 10m size were laid out across the three forest types. The number of sampling plots was decided in order to minimize error of the estimates as compared to previous study carried out in 1999. The size of the quadrat was kept same to maintain uniformity in measurement with the previous study. The number of sampling quadrats in earlier study was however, different, there were total of 31 units distributed as 13, 9, 9 across HMMF, OF, and MHF respectively. The distribution was according to the proportion of area covered by those forests. Since, this study was only confined at the lower half of the watershed, where substantial population of this system resides; more sampling plots were laid out in MHF mainly because of two reasons. First, it is believed that more variation in forest volume and biomass is in this forest. Second, in present study, the proportion of the area where MHF is present is greater than other area where two other forest types OF and HMMF are present (Table 1). Hence, I distributed 20 plots in MHF and 10 plots each in OF and HMMF.

Table 1 Study area and forest cover in Mardi watershed

Forest Types	Study area (ha) (and percentage)	Forest area (ha) in relation to total Mardi watershed area (Awasthi et al. 2002)
MHF	4460 (61.3%)	2488 ha (30% of forest area)
OF	1690 (23.2%)	2489 ha (30% of forest area)
HMMF	1120 (15.5%)	3318 ha (40% of forest area)
Total	7270 (100%)	8295 ha (58% of total watershed)

In the earlier study, the sampling plots were established along two transect lines systematically. However, the locations of the sampling plots were not clearly described. Hence, in this study, location of sampling plots was selected through stratified random sampling. One reason to choose this method was because stratified random sampling increases accuracy of population estimates (Cochran 1977).

In this regard, first, the area of the watershed was divided into three non-overlapping parts according to three forest types namely, MHF, OF, and HMMF. For this task of delineation of study area and the three forest strata, Mountain geo-portal database (MENRIS/ICIMOD 2012) and previous studies (Awasthi et al. 2002; Gurung et al. 2002) were followed. A topographic land cover map of the area was used as a reference map (scale 1:50000). The map was then gridded (5mm × 5mm grids) and overlaid with the forest strata made above. Then, a layer of all crossing points lying just above the forest cover on each overlaid strata was made. In this way, three separate vector layers of points for all three forest types were prepared. Each of the crossing point has been assigned a particular number. Afterwards, of the above all points, 20 numbers from MHF, 10 from OF and 10 from HMMF were randomly selected. Finally, a combined layer of 40 sampling plots was made ready for field work (Appendix 1). Quantum GIS (1.7.0 Wroclaw), an open source software was used in executing this task. However, statistical software R was used for random sampling. There was possibility that some of the sampling points prepared could lie outside the forest at the field. In that case, a field protocol was also made to collect sample from the nearest forest from that point.

2.4 Field Data

The field data were collected during November-December 2012 from the 40 sampling quadrats with size 10m × 10m distributed randomly across the three forest types (Figure 1). Garmin GPS Map 62S was used to navigate to the sampling plots. A Compass and a measuring tape (50 m) were used to enclose a sampling plot. On all plots, diameter at breast height (dbh, 1.3 meter above the ground) for every tree with dbh ≥10 cm was measured with a diameter tape (Lufkin, Executive Thin Line, 2m) and identified by species. The reference book (Storrs & Storrs 1990) was also accompanied for identification of trees. Tree heights (in meter) were also measured with hypsometer (Vertex III with Transponder). Altitude (masl), slope angle, distance from the nearest human settlement, and aspect of each of the sampling plots were also recorded. Altitude from mean sea level was recorded with Garmin GPS Map 62 S. Slope angle was measured with Clinometers (Suunto PM-5/360 PC). Aspect of the sampling plot was recorded with Compass.

The distance of the sampling plot from the nearest village was measured in QGIS from the vector layer of the waypoints imported from Garmin GPS.

2.5 Calculation of Over Bark Stem Volume and Total above Ground Biomass

For most of the Nepalese trees species, over bark stem volume is calculated mainly by the logarithmic equation developed by Sharma and Pukkala (1990). The equation is:

$$LN(V) = a + b*LN(d) + c*LN(h) \quad \text{……………………… (1)}$$

Where, a, b, and c are species specific parameters

V is the over bark stem Volume

d is the diameter at breast height (cm)

h is the tree height (m)

However, I have used the modified version of above equation which gives over bark stem volume (m3) directly with diameter at breast height and tree height as independent inputs. This equation was also used by the baseline of this study conducted in 1999. The modified version of the above equation is,

$$V = Exp(a + b*LN(d) + c*LN(h))/1000 \quad \text{…………………… (2)}$$

The logarithmic equation developed by Sharma and Pukkala (1990) is the most widely used volume and biomass estimation model till this date mainly due to its applicability to wide group of tree species. However, this publication has species specific parameters for only 21 tree species. For the rest of the species, this publication has two miscellaneous species specific parameters developed for miscellaneous tree species in Terai (a low lying flat ecological zone in Nepal) and Miscellaneous tree species in Hills separately. Hence, for the trees to which specific parameters are not known, the values developed for miscellaneous hill species were used in the calculations.

Since, this study was concerned only with total above ground biomass, underground biomass has not been considered in calculation. Stem biomass, branch biomass and foliage biomass were calculated. The stem biomass of the tree was calculated by multiplying over bark stem volume with specific wood density. The volume table has wood density for only 21 species but not for other two miscellaneous groups mentioned above. Hence, for all the species to which wood density is not known, I have followed master plan for the forestry sector in Nepal (HMGN/ADB/FINNIDA 1988). The branch biomass and foliage biomass were calculated as per the ratios developed by HMGN/ADB/FINNIDA (1988). The table has separate ratios for three diameter classes: small trees (dbh<28 cm), medium trees (dbh 28-53 cm) and big trees (dbh>53 cm). In case of species without particular ratios mentioned, ratio for miscellaneous hill species and other mixed hardwoods were used based on the forest types. The stem, branch and foliage biomass were summed to get the total biomass. All plot wise stem volume and total biomass were then scaled to m^3 ha^{-1} and tons ha^{-1} because it can be easily compared to that of other locations and it is independent of the sampling plot size.

2.6 Statistical Analysis

MS Excel and statistical software R were used in data analysis. Shapiro-Wilk test of normality was done for stem volume and total biomass for all forest types separately. The test statistics for mixed hardwood forest (MHF) for both volume and biomass were less than $\alpha=0.05$. However, for oak forest (OF) and high mountain mixed forest (HMMF) the p-values were greater than 0.05. Therefore, the data was transformed into log normal and tried normality tests. But, in either case, p-values were almost identical. Hence, I assumed my data to be normally distributed and performed parametric test algorithms.

Student t-test was used to compare means. Mean, standard error and coefficient of variation for all the variables were calculated. Linear regression was also carried out taking total biomass as the dependent variable and accessibility, altitude, slope angle and aspect as the independent variables. Variation in stem volume and biomass in relation to different independent variable classes was also analyzed with one way analysis of variance. But, since this study was not carried out in entire watershed as that of earlier study done in 1999, this time, some of the explanatory variable classes (Accessibility, Aspect) were classified differently (Table 2).

Table 2 Explanatory variables and their classes

Explanatory variables	Variable classes		
Altitude	Low <1800m	Medium 1800-2400 m	High >2400 m
Slope	Low <30 degree	High >30 degree	
Accessibility	High <2 km	Medium 2-3 km	Low >3km
Aspect	East	North-West	South-East

In the preset study, the sampling plot with lowest accessibility was not more than 4.5 km. Hence, this class was classified differently. Aspect classes were also of 5 types in this study; however, previous study had only three aspect classes. Since, five aspect classes found couldn't be merged into three; volume and biomass in three aspects classes mentioned by previous study were only compared.

3. Results

3.1 Current Status of Over Bark Stem Volume and Total above ground Biomass

Mean, standard error of the mean (SEM), and coefficient of variation (CV) for independent variables namely distance from nearest settlement, slope angle and altitude in three forest types are presented in Table 3. The High Mountain mixed forest is comparatively far from human settlement and at high altitude. However, Mixed hardwood Forest lies close to human settlements and at lower altitude. Oak forest showed variables average value in between MHF and HMM forest. Slope angle, however, is more or less same in all three forest types.

Table 3 Descriptive Statistics for various explanatory variables in relation to forest types

Forest Types	Descriptive statistics	Distance from nearest settlements (km)	Slope angle (degree)	Altitude (masl)
MHF	Mean	1.0	30.5	1293.4
	SEM	11.3	146.6	47.9
	CV	48.7	21.5	16.6
OF	Mean	2.4	32.5	1808.3
	SEM	18.5	132.0	92.0
	CV	24.7	12.9	16.1
HMMF	Mean	2.8	29.9	2299.0
	SEM	22.9	138.6	61.7
	CV	25.8	14.7	8.5

Similarly, mean, SEM and CV for over bark stem volume, three biomass components (stem, branch and foliage biomass), and total above ground biomass in the three forest types are presented in Table 4. The stem volume and biomass was significantly different among and between forests. Mean volume ha^{-1} in Oak Forest was found to be higher (755.9 ± 53.2) than High Mountain Mixed Forest (557.5 ± 31.1) and Mixed Hardwood Forest (282.5 ± 32.2). Similarly, mean total biomass ha^{-1} was also higher in Oak forest (1166.2 ± 113) as compared to

HMMF (766.4 ± 53.8) and HMF (302.5 ± 32.1). Of the three types, MHF had stem volume only a third of that found in OF and half of that in HMMF (Figure 5).

Table 4 Descriptive Statistics for over bark Stem volume (m^3 ha^{-1}) and Biomass (tons ha^{-1}) among forest types

Forest Types	Descriptive Statistics	Stem Volume	Stem Biomass	Branch Biomass	Leaf Biomass	Total Biomass
MHF	Mean	282.5	180.7	107.2	14.6	302.5
	SEM	32.2	21.0	12.9	1.6	32.1
	CV	51.0	52.0	53.8	50.4	47.4
OF	Mean	755.9	530.0	531.0	105.1	1166.2
	SEM	53.2	49.7	52.8	10.9	113.0
	CV	22.3	29.6	31.5	32.7	30.6
HMMF	Mean	557.5	357.6	329.9	79.0	766.4
	SEM	31.1	23.2	27.0	4.1	53.8
	CV	17.6	20.5	25.9	16.4	22.2

A total of 48 tree species were encountered in this study. Of the 40 sampling plots, 8 plots hit outside the forest. Hence, the samples were taken from the nearest forest form those locations. The density of stems ha^{-1} by diameter class in three forest types is presented in Figure 2. The total number of stems for diameter class I (dbh<20 cm) was higher in HMMF (590 stems ha^{-1}) compared to OF (420 stems ha^{-1}) and HMF (435 stems ha^{-1}). Oak forest demonstrated slightly less density of stems than other two forest types in this diameter class. The density of medium sized trees (diameter class II, dbh 20-50 cm) was higher in Oak Forest (550 stems ha^{-1}) than High Mountain Mixed Forest (540 stems ha^{-1}) and Mixed hardwood Forest (350 stems ha^{-1}). In case of big trees (diameter class III, dbh >50 cm), the number of trees was still higher in Oak Forest than High mountain mixed Forest and Mixed hardwood forest. The total number of stems was however, higher in High mountain mixed forest (1260 stems ha^{-1}) followed by Oak Forest (1130 stems ha^{-1}) and Mixed hardwood forest (805 stems ha^{-1}).

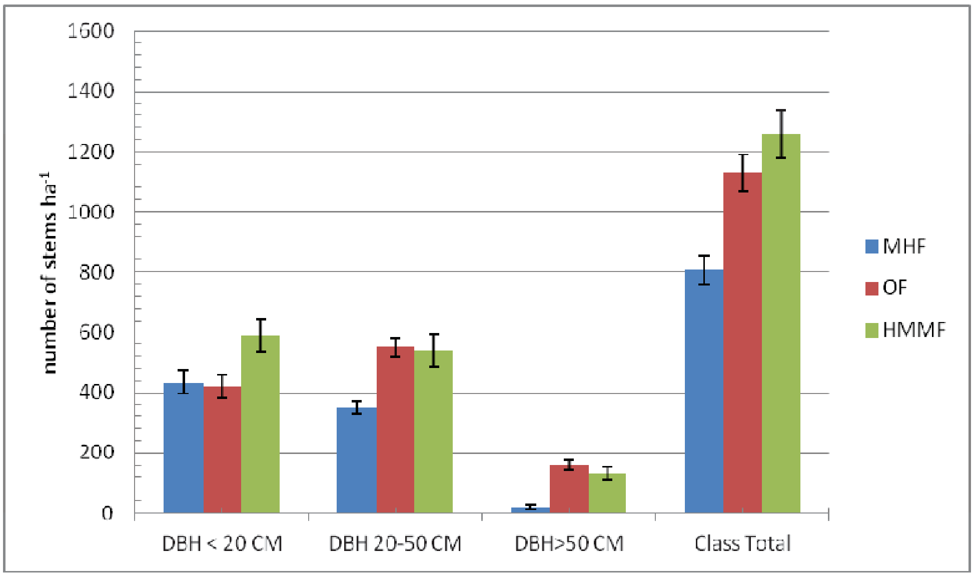

Figure 2 Number of Stems ha^{-1} by diameter class in three forest types (error bars- SEM)

The distribution and the allocation of stem volume and total biomass in relation to different diameter classes in the three forest types are presented in Table 5.

Table 5 Mean volume and biomass (± SEM) according to diameter class in three forest types.

Forest Types	Diameter class	Volume (m^3 ha^{-1})	Biomass (tons ha^{-1})
Mixed Hardwood Forest	CLASS I	48.7 ± 0.5	50.4 ± 0.5
	CLASS II	184.4 ± 14.9	205.6 ± 19.2
	CLASS III	49.4 ± 53.6	46.5 ± 34.6
Oak Forest	CLASS I	35.7 ± 0.6	44.4 ± 1.0
	CLASS II	299.1 ± 5.4	399.3 ± 8.3
	CLASS III	421.1 ± 37.9	722.5 ± 83.9
High Mountain Mixed Forest	CLASS I	53.5 ± 0.5	63.9 ± 0.6
	CLASS II	284.6 ± 3.7	376.1 ± 5.3
	CLASS III	219.3 ± 7.2	326.4 ± 23.6
All forest types	CLASS I	46.7 ± 0.4	52.2 ± 0.4
	CLASS II	238.2 ± 2.3	296.6 ± 3.4
	CLASS III	184.8 ± 20.7	285.5 ± 45.0

The mean stem volume of diameter class I trees in Mixed hardwood forest (48.7 ± 0.5) was less than High mountain mixed forest (53.5 ± 0.5) but greater than Oak forest (35.7 ± 0.6). However, in rest of the two diameter classes, the mean stem volume and total biomass was higher in Oak Forest followed by High Mountain mixed forest and Mixed Hardwood forest (Table 5). The result shows higher proportions of volume and biomass are presented in large trees in OF and HMMF. However, in case of MHF large trees reported relatively lower proportion of volume and biomass stored.

The histogram of tree stands as per the diameter class in all forest is shown in Figure 3. The figure shows decrease in number of stems with increasing DBH, indicating natural regeneration in the forest with inverse J distribution. The distribution of diameter at breast height (DBH) and tree height in all three forest types is shown in Figure 4 which shows dominance of relatively taller trees in MHF as compared to HMMF.

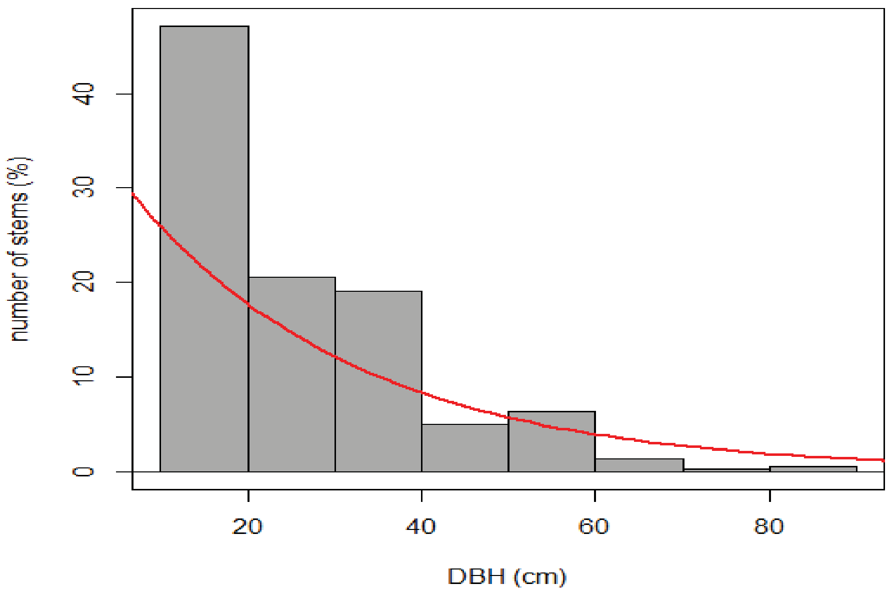

Figure 3 Histogram of stem density according to DBH in all forests (red line: negative exponential function)

The result of analysis of variance exhibited significant variation in forest volume and biomass in terms of forest types, distance classes, and altitude (Table 8). The variability between volume and biomass in forest close and far from human settlement was significant. Similarly, significant variation has been found in volume and biomass between high and medium accessibility. However, there appeared marginal difference in mean volume and biomass between forest with medium and low accessibility. In this study variation in biomass and stem volume in different aspects and slope angle was not significant.

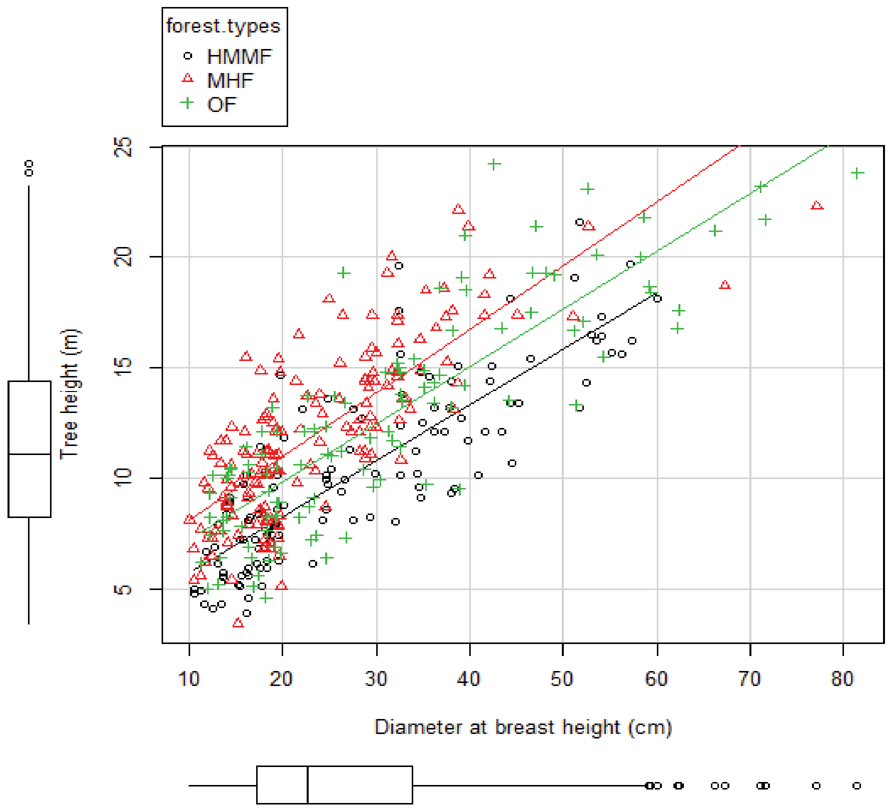

Figure 4 DBH and Tree height in three forest types

The result of multiple linear regressions with Biomass as dependent variable and altitude, distance from settlement, and slope as independent variables is presented in Table 6. Various combinations of variables were regressed to see the relationships between them.

Table 6 Total biomass function according to forest types

Forest Type	Estimates of regression coefficient with respect to				R^2	Degree of Freedom
	Altitude	Distance	Slope	Y-intercept		
MHF	0.00147	1.72***	-0.037	0.40	0.33	16
OF	0.0042 #***	3.71*	0.06	-6.78 #*	0.89	6
HMMF	0.003*#***	1.60**	-0.05	-2.16	0.80	6
ALL FOREST	$-7.54e^{-05}$ #***	3.47***	$3.19e^{-02}$	$-8.01e^{-01}$	0.64	36

Significance Codes: 0.001 '***' 0.01 '**' 0.05 '*', #* - significance only with Altitude and slope, excluding distance.

3.2 Change in forest volume and Biomass between 1999 and 2012

In comparison of recent results with estimates of 1999, the change in stem volume, total above ground biomass, and biomass components was not significant (Table 7, Table 9) between the two measurements. However, there was marginal increment in stem volume and biomass in the same period (Figure 6, Figure 7). Among the forest types, the higher average increment of stem volume was found to be in MHF (49.9 m^3 ha^{-1}) followed by OF with average increment of 44.9 m^3 ha^{-1} and HMMF with increment of 44.8 m^3 ha^{-1} in stem volume. MHF demonstrated 21% increment in stem volume between these two periods. However, OF and HMMF showed 6% and 8% respectively. In case of total biomass, MHF showed the lowest increase (31.7 tons ha^{-1}). Oak Forest was found to have highest increase in total biomass followed by High Mountain mixed forest. OF and HMMF reported 13% increment in total biomass where as MHF showed 12 % increment in total biomass.

If we assume that the total forest cover of the Mardi watershed is same as reported by Awasthi et al. (2002) during this period (Table 1), and calculate the change in stem volume and total above ground biomass in the three forest types combined together; it can be estimated that there was an increment of 46.3 m^3 ha^{-1} in stem volume and 87.8 tons ha^{-1} in biomass between 1999 and 2012. The same figure can also be interpreted as increment of 3.56 m^3 ha^{-1} yr^{-1} in stem volume and 6.76 tons $ha^{-1}yr^{-1}$ in total above ground biomass. The carbon sequestered between these periods can then be estimated as half of the increased total above ground biomass, which will be equal to 3.38 tons of carbon ha^{-1} yr^{-1}.

Table 7 Changes in forest attributes between 1999 and 2012

Forest types	Attributes	2012	1999	Difference	% Change	p-value
MHF	Stem volume (m^3 ha^{-1})	282.5	232.6	49.9	21.4	0.483
	total biomass (tons ha^{-1})	302.5	270.8	31.7	11.7	0.710
	Stem biomass (tons ha^{-1})	180.7	147.1	33.6	22.8	0.437
	Branch biomass (tons ha^{-1})	107.2	105.8	1.4	1.3	0.972
	Foliage biomass (tons ha^{-1})	14.6	17.9	-3.3	-18.4	0.542
OF	Stem volume (m^3 ha^{-1})	755.9	711	44.9	6.3	0.705
	total biomass (tons ha^{-1})	1166.2	1026.7	139.5	13.6	0.493
	Stem biomass (tons ha^{-1})	530	485.9	44.1	9	0.615
	Branch biomass (tons ha^{-1})	531	447.3	83.7	18.7	0.412
	Foliage biomass (tons ha^{-1})	105.1	93.5	11.6	12.4	0.600
HMMF	Stem volume (m^3 ha^{-1})	557.5	512.7	44.8	8.7	0.585
	total biomass (tons ha^{-1})	766.4	675.1	91.3	13.5	0.441
	Stem biomass (tons ha^{-1})	357.6	314.8	42.8	13.6	0.419
	Branch biomass (tons ha^{-1})	329.9	282.7	47.2	16.6	0.349
	Foliage biomass (tons ha^{-1})	79.0	77.6	1.4	1.8	0.935

Among the three forest types, in MHF, stem biomass and branch biomass were found to have increased by 33.6 tons ha^{-1} and 1.4 ton ha^{-1} respectively during this time. However, foliage biomass was decreased by 3.3 tons ha^{-1} (Figure 8). The biomass in oak forest was increased by 139.5 tons ha^{-1} over 13 years. Stem biomass showed increment of 44.1 tons ha^{-1} whereas branch and foliage biomass increased by 83.7 tons ha^{-1} and 11.6 tons ha^{-1} respectively (Figure 9). Similarly in HMMF, stem, branch and foliage biomass were increased by 42.8 tons ha^{-1}, 47.2 tons ha^{-1}, and 1.4 tons ha^{-1} respectively since 1999 (Figure 10).

Among the studied variables, in the three altitude classes, the increment in total above ground biomass in forest located at higher altitude was statistically significant (p-value 0.017) between these periods (Table 9). However, other altitude classes did not show significant changes. In the accessibility classes, the comparisons of stem volume and total above ground biomass between 1999 and 2012 revealed significant changes in forest with low accessibility (Table 9). The comparison also showed significant change in total above ground biomass in forest situated near to human settlement. The forest with medium accessibility however demonstrated marginal difference between two measurements. Similarly, changes in stem volume and total above ground biomass were not significant in slope angle classes and aspect classes.

Table 8 Analysis of variance in mean stem volume (m^3ha^{-1}) and mean total above ground biomass (tons ha^{-1}) with respect to variable classes

Variable Classes	n	Mean ± SEM		Comparison of means	P-value	
		Volume	Biomass		Volume	Biomass
MHF	20	282.5 ± 32.2	302.5 ± 32.1	MHF- OF	<0.001***	<0.001***
OF	10	755.9 ± 53.2	1166.2 ± 113	OF- HMMF	0.0088**	<0.0007***
HMMF	10	557.5 ± 31.1	766.4 ± 53.8	HMMF-HMF	<0.001***	<0.001***
				ALL CLASSES	<0.001***	<0.001***
ALT 1	25	370.1 ± 44.8	447.6 ± 66.7	ALT1-ALT2	0.0027**	0.00105 **
ALT2	12	634.7 ± 59.3	946.4 ± 123.1	ALT2-ALT3	0.999	0.999
ALT3	3	638.6 ± 29.7	942.6 ± 46.4	ALT3-ALT1	0.105	0.067*
				ALL CLASSES	0.0021**	0.0005***
D1	25	324.3 ± 31.9	374.2 ± 40.7	D1-D2	<0.001***	<0.001***
D2	9	686.7 ± 46.8	1013.7 ± 96.9	D2-D3	0.727	0.573
D3	6	749.5 ± 69.3	1149.5 ± 159	D3-D1	<0.001***	<0.001***
				ALL CLASSES	<0.001***	<0.001***
S1	20	434.8 ± 46.0	544.5 ± 66.8	S1-S2	0.374	0.184
S2	20	504.5 ± 62.4	724.3 ± 114.6			
E	5	425.0 ± 92.0	535.3 ± 140.1	E-NW	0.889	0.946
NW	4	275.4 ± 94.6	325.4 ± 141.4	NW-SE	0.445	0.560
SE	16	507.6 ± 60.5	684.6 ± 103.9	SE-E	0.963	0.958
N	12	499.0 ± 80.0	702.1 ± 148.7	N-E	0.978	0.945
W	3	482.9 ± 152.3	673.6 ± 235.4	W-E	0.997	0.991
				NW-N	0.514	0.546
				SE-N	1.000	1.000
				W-N	1.000	1.000
				W-NW	0.797	0.817
				W-SE	1.000	1.000
				ALL CLASSES	0.535	0.586

***= Significant at 1 percent level, **= Significant at 5 percent level, *= Significant at 10 percent level

n= number of quadrats

MHF, OF, HMMF are three forest types

ALT1, ALT2, ALT3 are three Altitude class from low to high respectively

D1, D2, D3 are three accessibility classes from high, medium, and low respectively

E, NW, SE, N, and W are aspect classes respectively east, northwest, south east, north, and west

S1, S2 are slope angle classes, S1 $<30^0$, S2$>30^0$

Table 9 Comparison of stem volume and total above ground biomass between 1999 and 2012

Variable classes	2012 Mean ± SEM		n	1999 Mean ± SEM		n	Comparison P- Value	
	Volume	Biomass		Volume	Biomass		Volume	Biomass
MHF	282.5 ± 32.2	302.5 ± 32.1	20	232.6 ± 62.4	270.8 ± 77.9	9	0.483	0.710
OF	755.9 ± 53.2	1166.2 ± 113	10	711 ± 104.0	1026.7 ± 164.0	9	0.705	0.493
HMMF	557.5 ± 31.1	766.4 ± 53.8	10	512.7 ± 74.6	675.1 ± 103.0	13	0.585	0.441
ALT 1	370.1 ± 44.8	447.6 ± 66.7	25	295.6 ± 78.7	329.1 ± 91.2	8	0.417	0.302
ALT2	634.7 ± 59.3	946.4 ± 123.1	12	580.2 ± 102.0	837.6 ± 155.0	14	0.648	0.588
ALT3	638.6 ± 29.7	942.6 ± 46.4	3	518.9 ± 64.7	677.3 ± 80.6	9	0.124	0.017**
D1	324.3 ± 31.9	374.2 ± 40.7	25	217.3 ± 75.4	236.5 ± 70.0	6	0.202	0.100*
D2	686.7 ± 46.8	1013.7 ± 96.9	9	593.7 ± 97.0	773.0 ± 146.0	8	0.401	0.190
D3	749.5 ± 69.3	1149.5 ± 159	6	535.5 ± 79.3	755.9 ± 120.0	17	0.055*	0.061*
E	425.0 ± 92.0	535.3 ± 140.1	5	548.2 ± 81.6	768.8 ± 112.0	6	0.343	0.225
NW	275.4 ± 94.6	325.4 ± 141.4	4	522.8 ± 156.0	743.1 ± 246.0	8	0.205	0.172
SE	507.6 ± 60.5	684.6 ± 103.9	16	484.7 ± 85.3	642.4 ± 119.0	13	0.829	0.791
S1	434.8 ± 46.0	544.5 ± 66.8	20	425.7 ± 63.2	589.0 ± 95.7	18	0.908	0.705
S2	504.5 ± 62.4	724.3 ± 114.6	20	576.6 ± 101.0	757.9 ± 152.0	13	0.548	0.861

***= Significant at 1 percent level, **= Significant at 5 percent level, *= Significant at 10 percent level

n= number of quadrats

MHF, OF, HMMF are three forest types

ALT1, ALT2, ALT3 are three Altitude class from low to high respectively

D1, D2, D3 are three accessibility classes from high, medium, and low respectively

E, NW, SE, are aspect classes respectively east, northwest, and south east

S1, S2 are slope angle classes, S1 $<30^0$, S2 $>30^0$

Table 10 Average tree size by forest types

Forest types	Mean dbh (cm)	Mean height (m)
HMMF	27.5	10.1
OF	30.4	12.5
MHF	23.6	12.0

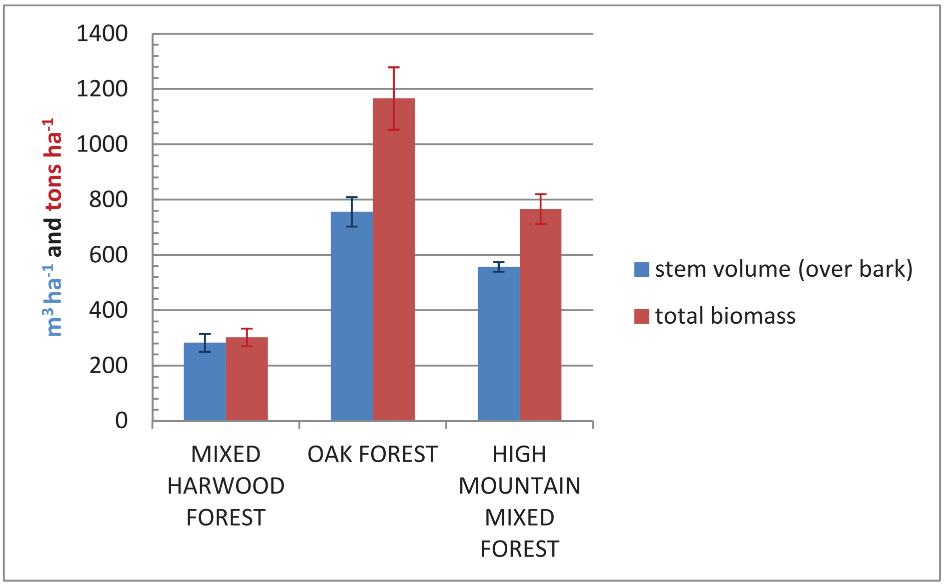

Figure 5 Mean over bark stem volume and total biomass in different forest types (error bars: SEM)

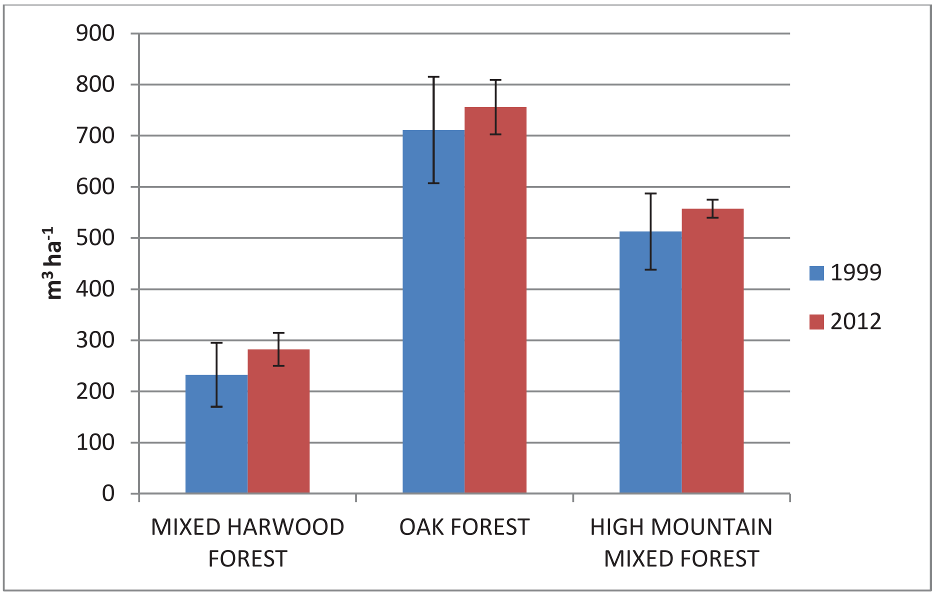

Figure 6 change in stem volume during the period of 1999-2012 (error bars: SEM)

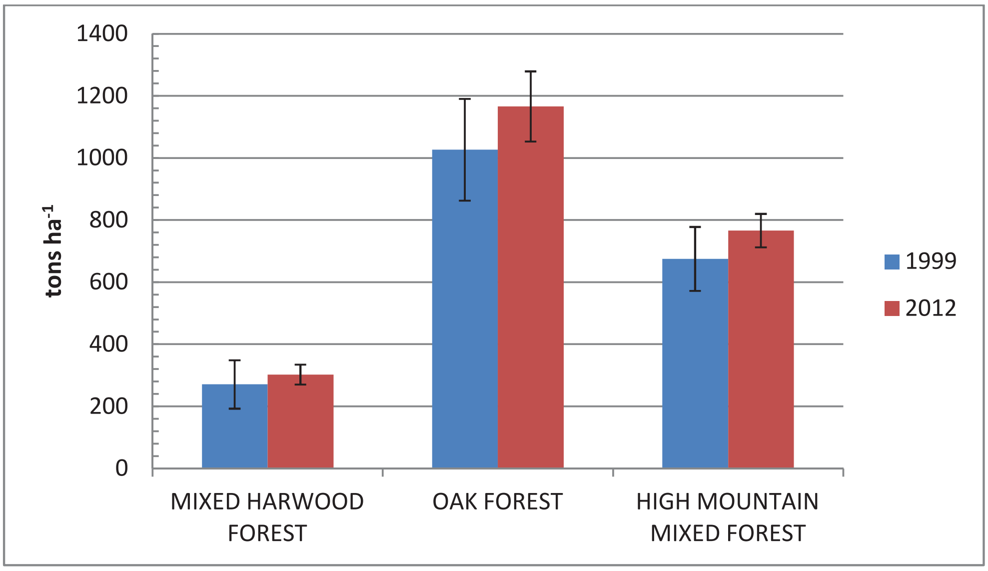

Figure 7 Change in total above ground biomass in three forest types (error bars: SEM)

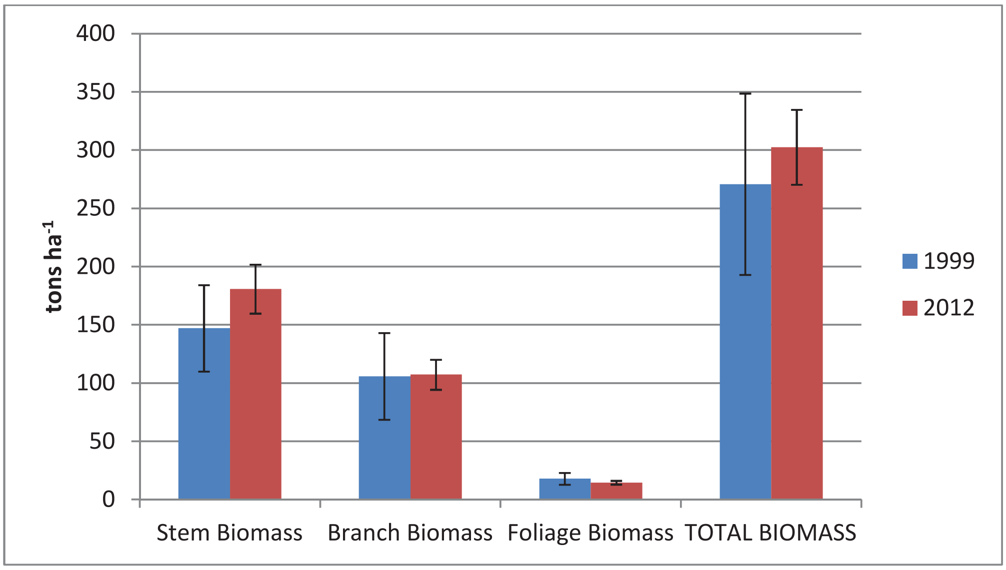

Figure 8 Change in biomass components in MHF (error bars: SEM)

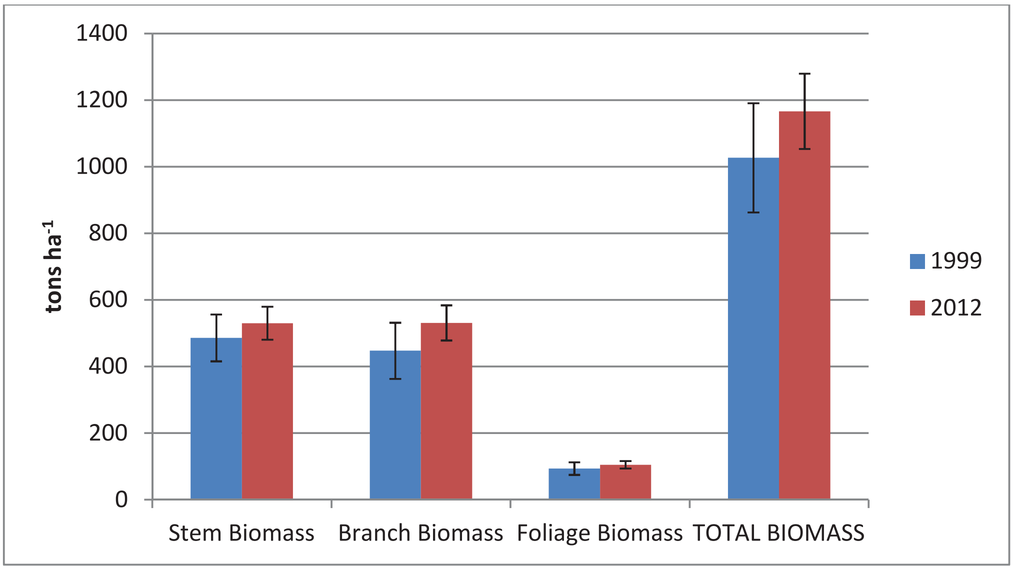

Figure 9 Change in biomass components in OF (error bars: SEM)

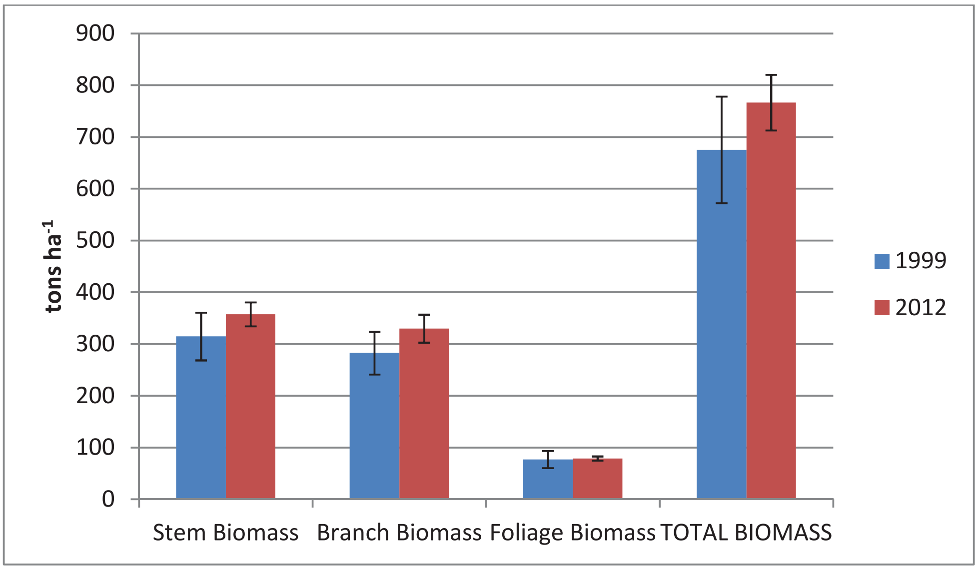

Figure 10 Change in biomass components in HMMF (error bars: SEM)

4. Discussion

The present study provides information about recent status of forest in lower half of Mardi watershed. This study also provides an insight into temporal changes in stem volume and biomass estimates between 1999 and 2012 AD. I will discuss about these two facets separately under the two subheadings.

4.1 Current status of forest volume and biomass

In this study, a significant variation was observed in terms of stem volume and biomass among and between the three forest types MHF, OF, and HMMF. The spatial variation of forest biomass, however, is not uncommon in heterogeneous landscapes (Clark & Clark 2000; Hoshizaki et al. 2004; Lamsal et al. 2012; Li et al. 2011; Sharma et al. 2008) . Nepal, with diverse topography within a short distance, naturally demonstrates multifaceted heterogeneity in landscapes (Metz 1989) and consequent variation in structure and composition of vegetation within these landscapes (Carpenter & Zomer 1996; Shrestha 2001; Stainton 1972). Hence, being a typical Nepalese mid-hill landscape, such kind of variation can be anticipated in Mardi watershed too. Besides several underlying bio-climatic factors; differences in forest composition, age and size of the tree, together with variation in tree density could possibly bring about this type of dissimilarity in volume and biomass among forest types. However, there are scarce publications explaining variation in volume and biomass among these ecological zones in Nepal. A few publications (Baral, S. K. et al. 2010; Shrestha & Singh 2008; Shrestha 2010; Subedi 2004) pointed out site condition, variation in stand density, growing nature of stand, variation in management regimes and forest types as reasons for significant difference in biomass between forests. Gurung et al. (2002) figured out two explanations for this difference - abandonment of transhumance, a common livestock management practice, in this region after 1970's and subsequent establishment of management and conservation institutions helped in recovering previously degraded forests. Since HMMF and OF are located far from human settlements they recuperated in a better way as compared to MHF. MHF couldn't regain its vigor due to its proximity to human settlements. Consequently, variation in forest attributes between MHF and other two forest types (HMMF, OF) continued and remained until now. However, after conservation and management tasks of this area were overtaken by communities, MHF is also improving. The land use change study during 1978-1996 in this watershed reported 2.4% increase in overall forest cover (Awasthi et al. 2002) which could be an indication that recovery after ecosystem disturbance has taken place in HMMF, OF and also in MHF gradually. The variation between OF and HMMF could be due to the differences in tree size and stem density, and higher wood density of oaks. Moreover, bio-climatic differences can also cause variation in biomass along its gradient (Garkoti & Singh 1995) as HMMF lies at higher altitude than OF. The paucity of studies explaining variation in volume and biomass along ecological zones in Nepal hence demands the need of detailed future studies with inclusion of multiple ecological and physiographic factors.

Within a single forest type, the higher variability in stem volume, total biomass, as well as three biomass components was seen in MHF. Field observations indicated that this forest showed remarkable variation in growth stage of trees ranging from highly mature and relatively undisturbed forest to a patch with recent regeneration. Since this type of forest is located close to human settlement, it is not surprising that some sample plots were found in disturbed forest (Li et al. 2011).

A forest resources inventory is now undergoing in Nepal (2010-2014), hence comparison of findings of this study cannot be done with the latest national and regional forest statistics at this point. However, in comparison to previous inventory data, the estimated stem volume and total biomass in all three forests in Mardi watershed were comparatively higher than regional and national averages in Nepal (FRISP 1999). The national forest inventory 1999 listed oak species second to *Shorea robusta* in terms of stem volume and biomass. The relatively higher stem volume and biomass in forest dominated by oaks in this study is in accordance with such listing.

MHF is dominated by *Schima* and *Castanopsis* species, but *Alnus nepalensis* is also a major associate. The mean biomass of MHF (302.5 tons ha^{-1}) in this study is within the range reported by Khatiy Chhetri (1999) in two *Schima-Castanopsis* forest with varying degree of disturbance. He reported mean standing biomass of 16 tons ha^{-1} in the severely disturbed forest to a maximum of 479 tons ha^{-1} in a relatively undisturbed forest. However, present estimate is higher than studies of (Shrestha 2010) done in Palpa where mean above ground biomass was reported to be 76.65 tons ha^{-1}. The recent estimate is also higher than another study in Palpa (Khanal et al. 2011) where *Schima-Castanopsis* natural forest had total aboveground biomass of 82.6 tons ha^{-1}. Similarly, the biomass is also higher in this type of forest in China as reported by Yang et al. (2010) where the total biomass of *Schima-Castanopsis* forest was 225.3 ton ha^{-1} of which the aboveground parts accounted for 162.2 tons ha^{-1}.

The study of Singh and Singh (1987) suggested the biomass range of central Himalayan forests between 163 tons ha^{-1} to 787 tons ha^{-1}, higher being in forest dominated by oaks. In the recent study the mean above ground biomass of oak forest (1166.2 tons ha^{-1}) is above this range. The present study showed higher biomass in oak forest compared to study of (Sati & Song 2012) who found 46 tons ha^{-1} in Uttaranchal India, and 550-600 tons ha^{-1} found in Kumau India at altitudes similar to the present study site by Singh et al. (1994). It is also well above the 325-355 tons ha^{-1} above ground biomass in oak forest reported by Verma et al. (2012); and 377.1 tons ha^{-1} of oak forest in central and western Himalaya found by Rawat and Singh (1988). The finding is also above the range 101-434 tons ha^{-1} reported by Sharma et al. (2010). In case of forest dominated by rhododendron with oaks as major associate, Koirala (2006) reported tree volume of 373.08 m^3 ha^{-1} and 371.14 m^3 ha^{-1} in non degraded and degraded forest respectively, in eastern mid-hill landscape, the recent finding of stem volume 557.5 m^3 ha^{-1} in HMMF is higher in this regard.

The number of trees in different diameter classes varies generally in forests (Coomes & Allen 2007). In this study also there were differences in number of stems per diameter class among the three forest types. Oak forest demonstrated a small gap, compared to MHF and HMMF, in small sized tree (dbh <20cm). It may be due to several factors hampering regeneration of oak. Måren and Vetaas (2007) also reported poor regeneration of oaks in Gorapani, in Annapurna conservation area, a site very close to Mardi watershed. However, in the other diameter classes, the dominance of oak forest was evident. Stem density in the three forest types were in general higher than national and regional averages (FRISP 1999; Pandey & Bajracharya 2011). Higher number of stems ha^{-1} in this study could be due to the location of this forest inside conservation area. Because in a similar study carried out in forests with two management regimes in Nepal, stem density in protected forest was significantly higher (Timilsina & Heinen 2008). Bajracharya et al. (2005) also found higher tree density inside Annapurna Conservation Area as compared to forest outside ACA. HMMF demonstrated higher stems with dbh <20 cm, suggesting relatively better status of regeneration in this forest. Måren and Vetaas (2007) also speculated higher favorability of regeneration and recruitment of rhododendron species in this conservation area. Diameter class distribution for all species combined was found to have slightly modified reverse J-shape; such kind of modification can be due to interplay of several factors affecting regeneration of some preferred species (Denslow 1995).

Among the three forest types, relatively taller trees were prevalent in MHF than HMMF. However, the average tree size was higher in OF. The distribution of volume and biomass within three diameter classes were also correlated with the stem density distributed among these forest types. Higher proportion of volume and biomass was distributed in medium diameter class trees in MHF. The smaller proportion of volume and biomass in MHF in diameter class III trees is mainly because of few trees (20 stems ha^{-1}) as compared to OF (160 stems ha^{-1}) and HMMF (130 stems ha^{-1}). OF and HMMF, on the other hand had higher number of large trees, and most of the volume and biomass was found in large trees. This is the principal reason for the difference observed in volume and biomass among forest types.

The analysis of variance exhibited significant variation in forest volume and biomass in terms of forest types, distance classes, and altitude. The possible explanation for variation in forest types has already been discussed. The variability between volume and biomass in forest with high and low as well as high and medium accessibility were significant. However, there appeared marginal difference in mean volume and biomass between forest with medium and low accessibility. In Nepal the population density is mainly centered at low altitude and decreases with increasing altitude (Hunter & Yonzon 1993). This is due to relatively higher prospects of agriculture and subsistence at lower altitude. The forests in low altitude are therefore in general under high pressure due to its proximity to human settlements. In this study, mean volume and biomass in this altitude class varied significantly from those in the medium and high altitude. However, volume and biomass in high altitude class and medium altitude class were marginally different. In this study, differences in biomass and stem volume in different aspects and slope angle were not evident. It may be due to the orientation of major ridges of Mardi watershed, it has two ridges both are running from north to south. Because of this structure, the region receives sun light throughout the year and hence exhibit only marginal variation in volume and biomass across its aspect classes. Stem volume and biomass were not different between slope angle classes in present study.

Multiple regressions carried out with biomass as response and altitude, distance, and slope as explanatory variable explained 89% of variability in biomass in oak forest. 80% of variability in high mountain mixed forest was explained by altitude and distance from settlement. However, in mixed hardwood forest only 33 % variability in biomass was explained by such factors.

4.2 Change in forest volume and biomass in Mardi watershed

Generally, change in forest biomass can be estimated accurately as a difference between consecutive forests inventories (Penman et al. 2003) performed on permanent sampling plots. However, in this study, we could not measure the same trees as previously assessed by Gurung et al. (2002) due to lack of information regarding exact location of sampling plots. It may be a source of error. But, the study site consisted of more or less distinct strata of forest types. Hence, I believe that random sampling drawn from each of these forests, at this point of time, could be compared with previous measurement to see the changes between the two periods.

In the present study, the analysis of forest measurements carried out at two different points of time did not reveal significant change. However, there appeared marginal changes in forest attributes in Mardi watershed. The change in forest volume and biomass in these forest types were not uniform. It is a common phenomenon that forest dynamics are not uniform between forest types (Chave et al. 2003). The dissimilarity of dominating vegetation between forest types differs highly in architecture and growth rate. With varying climatic condition, management regimes, and degree of resource extraction the forest system changes may vary greatly among forest types. The same has been found in Mardi watershed. Oak forest demonstrated higher increase in biomass as compared to HMMF and MHF, whereas, MHF had higher proportion of increment than OF and HMMF in terms of stem volume.

The present forest measurement revealed that the forest system in Mardi watershed showed marginal growth between 1999 and 2012. Forest volume in MHF, OF and HMMF increased by 21.4%, 6.3%, and 8.7% respectively. The higher increment in stem volume in MHF may be due to increased initiatives (conservation awareness, community plantations) taken in recent past towards the conservation and management of MHF by responsible authorities (ACAP, CAMCs, and locals). MHF lies in the intensive use zone and hence is on high conservation priority. Several plantations conducted especially in degraded areas of MHF may result in higher growth rate than OF and HMMF. Similarly, average increment in above ground biomass in MHF, OF, and HMMF were 11.7%, 13.6%, and 13.5% respectively during this period. There are studies with almost similar amount of biomass accumulation in highly productive mixed hardwood forest and forest dominated by oaks in some areas of the world (Curtis et al. 2002). The increase in forest volume and biomass could be due to various factors like decreased mortality rate, increase in forest productivity or interrelationship of both, together with expanded efforts in implementing forest conservation and management in this watershed under the leadership of ACAP and communities.

The change in biomass components within each forest type was not uniform in this study. In MHF, stem biomass and branch biomass increased by 22.8% and 1.3% respectively however; foliage biomass decreased by 18.4%. The positive change could be attributed to plantations initiatives carried out in past on degraded and deforested areas. The negative change could be due to influence of some big trees with high diameter at breast height but with relatively low height, which might have affected allometric biomass function. Intense lopping in the past for fuel and fodder or injury in past might have changed architecture of those trees. The lower estimate of biomass in MHF in the present study may also be due to inclusion of some species with lower wood density. For example, *Alnus nepalensis* is major species in all community plantation sites and has specific wood density lower than other species. Hence, in case of inclusion of more number of such species in the present study may alter biomass change estimation negatively. In case of OF and HMMF, increment of branch biomass and foliage biomass was greater than stem biomass. It may be an indication that these forests have prevalence of relatively mature trees with profound branches. HMMF and OF are located in protected forest zone in ACAP land use categories, on higher altitude far from human settlements, hence, the increment in this forest is admissible mainly due to its low degree of disturbance and higher degree of conservation.

The development of various biomass estimation models has made in-situ biomass calculation easy. But, the robust model for biomass estimation has not been made so far (Chave et al. 2005; Murali et al. 2005). Hence, the variation observed in the three biomass components in this study, could be due to the short comings of density values and biomass ratios for many species. During the calculation of biomass components, the three fixed ratios have been used for three groups of trees categorized according to diameter size. In absence of other calculation alternatives, the use of such ratios in the estimation of several biomass components could bring error. It is really a matter of query that how a fixed ratio can be robust in biomass estimation for many species.

Between the two measurements, increment in total above ground biomass in forest situated at higher altitude was significant. Forest at medium and low altitude exhibited marginal increment. Similarly, in forests with low accessibility, the increment in volume and biomass is significant since 1999. Altitude and accessibility were highly negatively correlated variables in this study. Hence, change in forest attributes in high altitude and low accessibility regions may be mainly due to relatively low extent of human interference. The comparison of mean volume and biomass between forests with medium accessibility in these two temporal scales however, exhibited marginal difference. There appeared significant change in forest biomass in forest with high accessibility between 1999 and 2012. The forest in this region showed significant increase in biomass. It could be attributed to efficient and prioritized conservation and management efforts in highly fragile MHF, collectively due to negligible withdrawal of forest resources, and plantation of fodder and fuel tree in degraded and private lands. The change in stem volume and biomass between 1999 and 2012 in relation to aspect were marginal. It may be due to orientation of Watershed. In case of comparison between slope classes, between these two time frames, the change was not significant.

For a country like Nepal, where large number of rural populace relies on forest resources, it is imperative to safeguard forests. It is noteworthy to mention that present study exhibited positive change in forest attributes especially in contemporary context of forest degradation (Brown et al. 1991; Gautam et al. 2004a; Panta et al. 2008; Upadhyay et al. 2005). Nepal has undergone several transformations in institutionalizing forest management paradigms since 1950's (Gautam et al. 2004b) . The nationalization of all forests during 1950' resulted in nationwide extensive forest degradation and deforestation. However, introduction of community forestry programme during 1970's has been instrumental in reshaping previously degraded forest resources in majority of mid-hills forested landscapes (Nagendra et al. 2008). The momentum of community involvement was so intense that, by 1999, about 10% of the total forest area was managed by ~8500 community forest user group (Agrawal & Ostrom 2001) and the study of Acharya (2005) reported about 1 million hectares of forest was under management of 13000 forest user groups. Department of Forest, government of Nepal reports about 25% of the total forest has now been managed by communities. The involvement of communities in conservation and management of natural resources has several benefits. The major benefit is, having sound understanding of local scenarios, communities' traditional knowledge and skills can bring effective and locally viable methodologies in the conservation and sustainable management of natural resources.

The bioclimatic characteristics of the watershed may be one reason which favors the growth of trees, because this part of ACA receives higher precipitation (MNR/MENRIS & ICIMOD 2008). Another reason for forest growth may also be due to reduced pressure because the region reported remarkable instances of out migration and foreign employment, and abandonment of agricultural lands (Aryal 2008). The comparison of two population figures (CBS 2012; Gurung et al. 2002) reports a difference of 2895 people in 2011 less than 1999. In addition to these, the recent positive change in forest system in Mardi watershed may mainly be attributed to its location. It is a part of conservation area where wide group of stakeholders have been involved in conservation, protection and management of forest resources. Moreover, ACAP has been instrumental in facilitating protection of natural resources in the entire conservation area since its inception in 1986. The introduction of integrated conservation and development programs has led to reduced pressure on forest resources and consequent improvement of natural resources in this area in general (Bajracharya et al. 2005; Gurung et al. 1994). The wellbeing of intact forest depends highly on the degree of habitat disruption and exploitation of forest products by the adjoining communities (Laurance et al. 2012) and hence the better state of forest in Mardi watershed can be an indication that the resources have been wisely utilized to some extent. Bajracharya et al. (2005) also found significant reduction of fodder and fuel wood collection from forests mainly due to increased conservation awareness, efficient use of fuel wood, plantation of fuel wood and fodder species on farm land, harvesting fuel wood from farm land, collection of only dry and dead wood, and access to alternative sources of energy.

Participatory conservation programs carried out in ACA also improved socio-economic development, environment, and biodiversity. As the study system consisted of complex medley of ethnic communities with varying degree of economical status, Kellert et al. (2000) suspected equitable delivery of conservation benefits among locals participated; because marginalized households without enough land to support their subsistence depend more on forest resources than other community members but receives relatively less benefits. This can impact attitude towards the community based conservation programs among the deprived people (Mehta & Kellert 1998). In spite of this, Mehta and Heinen (2001) and Bajracharya et al. (2006) found positive attitude of communities towards community led conservation initiatives in delivering socio-economic benefits such as improved access to forest resources, provision of drinking water, development of basic infrastructures- trails, bridges, access to health care facilities, sanitation, social services, and increased prospect of ecotourism. Tourism is also a main source of income for the people living here and ecotourism has had positive environmental and socio-economical impact in this area (Nyaupane & Thapa 2004). With increased tourism, however, the region experienced pressure on energy needs. To cope with such problems the intervention of ACAP in introducing alternative sources of energy to tourism sector is admirable (Nepal 2008). Ojha and Sarker (2012) has found increased wild life biodiversity through integrated conservation development program in ACA. But wild life biodiversity increase has caused crop damage in small fraction of farmers and led to some sort of conflicts (Bajracharya et al. 2006). But, in totality, with the ongoing conservation efforts, it can be inferred that environmental and socio-economical condition of the area has been improved and will continue in future too.

Being a protected area encompassing highly productive forests, Mardi watershed can get financial benefit from reducing green house gas emission from deforestation and forest degradation (REDD) programme. However, it needs scientific justification and present study can help, to some extent, in that respect. The forests in Mardi watershed are storing huge biomass and have been a carbon sink reducing atmospheric carbon dioxide during the last 13 years. The present study has shown that there has been an estimated net sequestration of 43.9 tons carbon ha^{-1} since 1999. The figure is equivalent to sequestration of 3.38 tons of carbon ha^{-1} yr^{-1}, which is slightly higher than average of 2.79 tons carbon ha^{-1} yr^{-1} reported by Karky and Skutsch (2010) in community managed forests in Nepal and India under normal management. Therefore, with the high conservation initiatives inside ACA, the forest of Mardi watershed can trap higher amount of carbon than other community managed forests. By doing so, these forests will continue to provide increased ecosystem services- environmental balance, increased productivity, provision of drinking water, ecotourism prospects, are to name few. Mardi River is the main source of drinking water for Pokhara, a nearby regional city. In that case, Mardi watershed can ask for payments for ecosystem services as a reward to the people involved in conservation and management of forest of this watershed.

Nepal went through decade long civil war during 1996 to 2006; as a result, several conservation initiatives were affected but ACA has been able to survive (Baral, N. et al. 2010). ACAP has been managed by NTNC since 1986, and had two times 10 year tenure extension in 1992 and 2002. The government on February 2013 has decided to extend its tenure by two more years (after its tenure expired on July 2012) and is going to handover the management of Annapurna conservation area completely to the local communities before this tenure expires. But, amidst the ongoing political instability and conflicts in almost all sectors within the country, this takeover may endanger ongoing conservation initiatives in absence of any efficient control mechanism. Therefore, formulation of appropriate policy guidelines, and efficient monitoring mechanism to ensure enhanced management of natural resources should be done before handing over management of ACAP to local communities. Only then, ACA can continue as a role model of community based nature conservation.

5. Conclusion

In conclusion, forests in Mardi watershed exhibited comparatively higher stem volume and total above ground biomass. Among the three forest types, the values were higher in oak forest followed by high mountain mixed forest and mixed hardwood forest. The stem volume and biomass showed significant difference in relation to forest types. The variation was explained by altitude and accessibility. However, average volume and biomass did not show difference due to aspect and slope angle. The stem density was also better in all three forest types. The analysis of temporal change in forest volume and biomass was not significant, though exhibited marginal change. All the three forest types in general exhibited minor increment in forest volume and biomass. Forest volume and biomass change was significant in forests located at higher altitude and with low accessibility. The change was marginal with respect to aspects and slope during the two measurements. The present finding shows better state of forest in Mardi watershed in terms of forest volume and total above ground biomass. This study will also serve the basis for monitoring future forest dynamics. The higher value of forest volume and biomass in the watershed may primarily be attributed to the conservation and management efforts carried out by communities and ACAP towards maintaining healthy and intact forests. However, in view of recent decision of giving management right of ACA completely to the community; it is imperative to design an efficient monitoring mechanism to ensure future conservation programs more effective.

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Appendix 1 Details of sampling plots

PLOT NO.	SAMPLING PLOTS ID	COORDINATES	
		LATITUDE N	LONGITUDE E
1	5	28° 20' 17.5"	83° 55' 10.2"
2	7	28° 20' 27.1"	83° 55' 8.4"
3	20	28° 20' 1.5"	83° 55' 29.8"
4	26	28° 22' 9.4"	83° 55' 25.8"
5	42	28° 22' 10.2"	83° 50' 48.1"
6	49	28° 21' 59.9"	83° 50' 56.4"
7	74	28° 21' 34.8"	83° 50' 42.9"
8	72	28° 21' 18.7"	83° 51' 2.9"
9	79	28° 20' 12.8"	83° 50' 36.4"
10	83	28° 18' 22.03"	83° 49' 34.0"
11	60	28° 18' 21.0"	83° 49' 43.9"
12	40	28° 19' 10.9"	83° 50' 37.8"
13	32	28° 19' 55.7"	83° 50' 37.1"
14	28	28° 20' 27.1"	83° 51' 12.8"
15	23	28° 20' 35.3"	83° 51' 49.4"
16	16	28° 21' 34.9"	83° 54' 53.8"
17	14	28° 21' 26.2"	83° 54' 44.2"
18	12	28° 20' 29.8"	83° 54' 34.4"
19	74	28° 19' 36.9"	83° 55' 12.4"
20	5	28° 19' 19.3"	83° 55' 23.7"
21	48	28° 18' 54.2"	83° 52' 28.4"
22	182	28° 18' 37.9"	83° 51' 6.3"
23	209	28° 19' 28.2"	83° 52' 27.2"
24	208	28° 20' 9.8"	83° 53' 3.7"
25	39	28° 18' 28.7"	83° 54' 19.0"
26	38	28° 21' 35.1"	83° 53' 48.7"
27	5	28° 19' 2.4"	83° 52' 28.1"
28	3	28° 19' 2.4"	83° 52' 9.7"
29	6	28° 19' 10.4"	83° 52' 2.9"
30	8	28° 19' 10.8"	83° 52' 18.6"
31	211	28° 19' 27.2"	83° 52' 36.7"
32	75	28° 19' 55.1"	83° 53' 3.0"
33	90	28° 20' 52.2"	83° 53' 36.0"
34	83	28° 20' 36.1"	83° 53' 14.1"
35	92	28° 20' 18.6"	83° 53' 31.2"
36	104	28° 18' 45.7"	83° 54' 49.9"
37	106	28° 21' 9.4"	83° 53' 48.7"
38	205	28° 19' 19.6"	83° 54' 35.8"
39	117	28° 19' 2.7"	83° 55' 13.2"
40	127	28° 17' 46.4"	83° 55' 33.8"

Pictures from the Field

Picture 1 Mardi watershed, a view from Lwang

Picture 2 A typical village, the two mountain peaks behind are Machhapuchhre and Mardi Himal

Picture 3 Community plantation

Picture 4 A glimpse of a forest at 2000 m