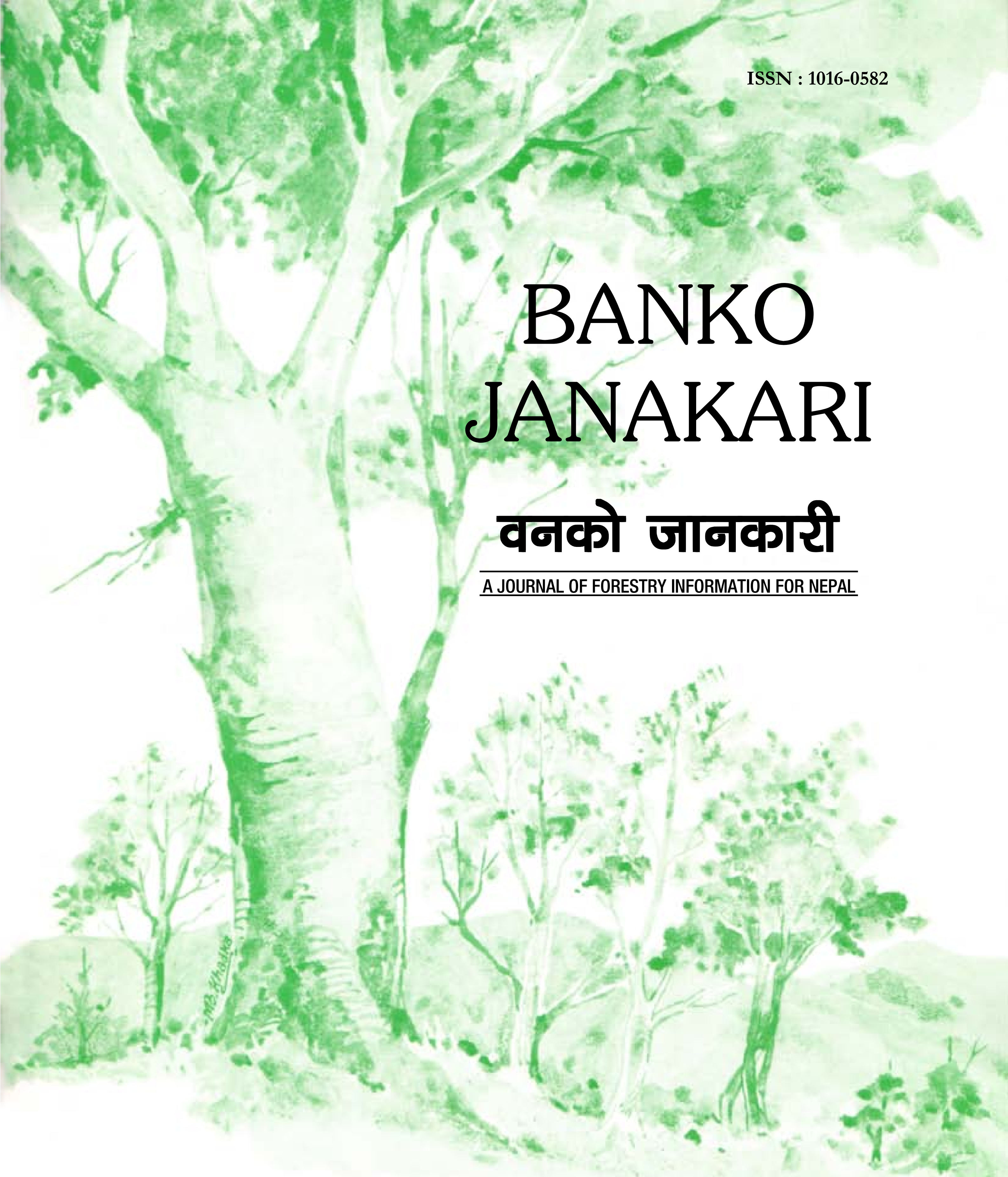

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Banko Janakari

A Journal of Forestry Information for Nepal

National forest resource assessment commences in Nepal

Forests have multiple environmental and socio-economic functions that are vital at global, national and local levels. Accurate, reliable, up-to-date and easily accessible information on the state of forest resources is crucial to support policy making and planning in forestry sector. In Nepal, the last National Forest Inventory (NFI) was carried out in the nineties. According to that inventory, forest and shrub together were found to cover 39.6% of the country's total land area. Till date, another NFI has not been carried out to update the forest resource database. Macro-level studies and visual observation have indicated that both forest coverage and condition in the hills have significantly improved due to intervention of community forestry. On the other hand, the valuable forest resources of the Terai belt of Nepal are getting degraded. The information based on the inventory of the nineties thus does not represent the present scenario. In this context, the Forest Resource Assessment in Nepal (FRA-Nepal) Project has started from January 2010 to update forest resource database.

FRA-Nepal is a forestry sector bilateral project funded by the Government of Finland for the period of five years (2010-2014) to conduct NFI in the country. The project is under the Ministry of Forests and Soil Conservation (MFSC). The Department of Forest Research and Survey (DFRS) is the implementing agency. The main objectives of the project are: (i) strengthening institutional capacity, (ii) maintaining forestry sector information system, and (iii) data sharing among forestry stakeholders. The project aims to generate national-level data regarding forest coverage (including the protected areas) and the types of forest, growing stock, wood and non-wood products, trees outside forest, and biological diversity.

New global issues such as climate change and Reducing Emissions from Deforestation and Forest Degradation in developing countries (REDD) are gaining importance in international arena, and demand updated forest cover map and carbon sequestration-related database to reveal change in the extent of forest cover and biomass. In this regard, FRA-Nepal project will facilitate to generate such datasets at national level.

The project will first assess the data needs through wide interaction among the forestry stakeholders. Methodological framework will then be finalized for NFI. After that, national-level forest resource data will be collected by using Remote Sensing technology and ground-based sampling. Under the multi-source data collection scheme, local stakeholders will also be engaged to ensure the best use of local knowledge and to improve ownership of data for future use. Both temporary and permanent sample plots will be laid out in the field, and measured. The state-of-the-art LiDAR (Light Detection and Ranging) technology will be used as a part of NFI to acquire complete information on forests from top of the canopy to the ground. The LiDAR technology has been found to be a promising technology that can give three-dimensional information regarding forest structures. This technology will, therefore, provide complete information about forest structure that is required for biomass calculations. Besides, Very High Resolution (VHR) satellite imagery will be used to detect trees outside forest. National- and regional-level thematic maps will be produced, and the forest resource database will be updated.

The updated forest resource database and maps will be useful for strategic management planning of valuable forest resources of Nepal. DFRS and FRA-Nepal Project anticipate support from all the stakeholders in this national endeavour.

Modelling height-diameter relationship for Chir pine trees

R.P. Sharma[1]

Tree height-diameter relationship can be used as an important input component in growth and yield models, and description of stand dynamics. This study aims at establishing robust height-diameter models for Chir pine (*Pinus roxburghii*) trees using regression techniques. Among the twelve non-linear models fitted to height-diameter data from twenty-three Chir pine stands in Parbat and Shyangja districts, Hossfeld's model accounted for the largest proportion of height variations (R^2_{adj} = 86%), and appeared to be biologically most realistic. This model can be applied to similar stand conditions from where study data were procured.

Keywords: Chir pine, height-diameter models, model evaluation, stand attributes

The accurate information of tree height is required for both forest management and research. Diameter at breast height (dbh) and total height are the commonly measured variables in an inventory. Unlike dbh, total height is less frequently used for construction or application of forest models because measurement of dbh is more cost effective, easy and accurate than total height. An estimation of total height from height-diameter models might be a reliable option where such models are available. For height-diameter models, a representative sample of accurately measured total-height is used as the response variable and dbh as the predictor variable. Several of such models are available in the literature (e.g. Curtis, 1967; Wang and Hann 1988; Huang *et al*., 1992, 2000; Moor *et al*., 1996; Zhang; 1997; Fang and Bailey, 1998; Sharma and Portan, 2007; Trincado *et al*., 2007; Newton and Amponsah, 2007; Wagle, 2007).

For a given species, height-diameter relationship differs from stand to stand due to different stand densities and site qualities, sometimes even within the same stand, variation might be high (Calama and Montero, 2004). Also, height-diameter relationship may change over time (Curtis, 1967). For more comprehensive and accurate height-diameter models, additional variables describing stand density (e.g. basal area or number of stems) and site quality (e.g. site index) should be included into the models (e.g. Sharma and Zhang, 2004; Tremesgen and Gadow, 2004; Sharma and Portan, 2007; Newton and Amponsah, 2007). However, getting information on such attributes demand a lot of resources, and therefore cannot be considered for general purpose models.

Chir pine (*Pinus roxburghii*) forest is located in a sub-tropical region with an altitude varying from 1000 m to 2000 m, and its standing volume is 6.3% of the total forest in the country (NFI/FINIDA, 1999). The economic contribution of Chir pine forest to national and local level development is valuable; and, therefore, its management is useful. For scientific management, species-specific individual tree or stand level models such as height-diameter models, site index models, growth models, and biomass and volume models need to be developed. Height-diameter models can be used as a sub-model (input) in the more comprehensive models such as biomass models, growth and yield models or their simulation systems. Modelling works for Chir pine forests in the country include Joshi, 1984; Joshi, 1985; Rauntiainen, 1992; and Sharma and Pukkala, 1990. But, none of these are height-diameter models. This study, therefore, aims at constructing height-diameter models using data from various Chir pine stands of two mid-hill districts.

Materials and methods

Data

Height-diameter data were obtained from Chir pine stands located in different localities such as Lunkhudeurali, Pakhapani, Kurgha, Falamkhani, Balakot, Bhorledanda, Ghantedeurali, Bayale, Karkineta, Khanigaun in Parbat and Syanja districts.

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Many of those stands, in that time, were managed in accordance with forest operation plans formulated by local users. The stands were visited during June-July in 2005. To cover wider variations of altitudes, aspects, slopes, stand origins (natural and plantation), stand densities, stand age and size classes and stand treatments, the selection of stands was subjective instead of using any complex sampling technique. Altogether twenty-three stands were selected for measurements.

Sample trees were chosen within each stand in such a way that the chosen trees would properly represent tree-population and micro-site of a subject stand. Measurements of deformed, top broken, suppressed, leaning and wolf trees were avoided. The number of sample trees varied from 5 to 31 within a stand, depending on variation of stand attributes. The diameter was measured with a diameter tape and total height was measured directly with a Vertex III Hypsometer. Due to higher accuracy of this instrument, the measured heights would be more precise, even on the slope. Because of not applying a plot inventory system, stand attributes such as stand density (basal area or number of stems), site index and stand ages were not recorded. The measurements of larger trees i.e., trees larger than 40 cm were mostly from old natural stands and those below 40cm were from young stands of plantation. Data summaries are presented in Table 1.

Models

Non-linear relationship between height and diameter was confirmed with a scattered plot diagram of height against dbh. Twelve different non-linear models (Table 2) were used to fit height-diameter relationship. All those models were parsimonious (possessing few parameters), mathematically robust, and therefore have been commonly used for modelling various tree and stand attributes (e.g. Wang and Hann, 1988; Huang *et al.*, 1992, 2000; Fang and Bailey, 1998; Sharma, 2006; Sharma and Portan, 2007; Newton and Amponsah, 2007). The models in Table 2 are of the following form:

$$H_i = 1.3 + f(Di, b) + \varepsilon_i \quad (1)$$

where H_i is the i^{th} observation of the response variable- tree height (m), D_i is the i^{th} observation of the predictor variable-dbh (cm), b is a vector of model parameters, and ε_i is the unexplained error, and it is assumed to be independent and normally distributed with a zero mean and a constant variance. A constant, 1.3 was added to the model to avoid prediction of a H_i less than 1.3 m when D_i approaches zero.

Analysis

Parameter estimation and model evaluation

The parameters were estimated using a non-linear least-squares procedure with full information maximum likelihood (FIML) methods in SAS/ETS PROC MODEL (SAS Institute, Inc. 2004). The fitted models were then evaluated using all of the following criteria:

1. *Significant parameter estimates*: Parameter estimates should be significantly different from zero ($p<0.05$).
2. *Akaike information criterion (AIC):* This is one of the most reliable criteria to compare the models with different parameter numbers (Burnham and

Table 1 : Data summary (dbh class (cm): 0-10 = 0-10.99, 11-20 = 11-20.99, and so on)

Variables (dbh, cm; height, m)	Number of observations	Mean	Minimum	Maximum
dbh (0-10)		7.6	0.8	10.9
height	71	7.9	1.6	13.9
dbh (11-20)		16.1	11.0	20.9
height	227	14.6	7.0	24.3
dbh (21-30)		24.9	21.0	30.9
height	210	20.5	13.9	29.5
dbh (31-40)		36.4	31.0	40.5
height	96	25.6	18.0	31.3
dbh (41-50)		44.0	41.0	50.9
height	35	28.5	23.2	34.0
dbh (51-60)		56.2	53.6	60.1
height	5	29.4	26.5	33.0
dbh (overall)		22.9	0.8	60.1
height	644	18.3	1.6	34.0

Table 2 : Models considered

	Models *	References
M1	$H = 1.3 + aD^b$	Arabatzis and Burkhart (1992)
M2	$H = 1.3 + a\exp\left(\frac{b}{D}\right)$	Buford (1986)
M3	$H = 1.3 + \exp(a + bD^c)$	Wang and Hann (1988)
M4	$H = 1.3 + a + bD + cD^2$	Curtis (1967)
M5	$H = 1.3 + \frac{D^2}{(a + bD + cD^2)}$	Huang *et al.* (1992)
M6	$H = 1.3 + aD^{(b+cD)}$	This study
M7	$H = 1.3 + \frac{aD^2}{(D+b)^2}$	Hossfeld (1822)
M8	$H = 1.3 + \frac{D^a}{b + cD^a}$	Hossfeld (1822)
M9	$H = 1.3 + a[1 - \exp(-bD)]^c$	Richards (1959), Chapman (1961)
M10	$H = 1.3 + a[1 - \exp(-bD)]^3$	Bertalanffy (1949)
M11	$H = 1.3 + \frac{a}{1 + b\exp(-cD)}$	Logistic model, cited in Zeide (1993)
M12	$H = 1.3 + a[1 - \exp(-bD^c)]$	Weibull model, cited in Zeide (1993)

*H = total height (m); D = dbh (cm); and a, b, c = parameters; exp = exponent

Anderson, 2002). The smaller the AIC value, the better the model. It is defined as:

$$AIC = f(\beta) + 2p \quad (2)$$

where $f(\beta)$ is negative of the marginal log-likelihood function, β is a vector of parameter estimates, and p is the number of parameters in a model.

3. *Root mean squared error (RMSE):* It is defined as:

$$RMSE = \sqrt{\frac{\sum_{i=1}^{n}\left(h_i - \hat{h}_i\right)^2}{n-p}} \quad (3)$$

where h_i and h_i are the observed and predicted values for the dominant height of observation i, respectively; n is total non-missing observations used to fit the model; and p is the number of parameters in the model.

4. *Adjusted coefficient of determination* (R^2_{adj}): This shows a proportion of total variance explained by the model with the adjustment of the number of parameters, p and the number of non-missing observations, n. It is estimated as:

$$R^2_{adj} = 1 - \frac{(n-1)\sum_{i=1}^{n}\left(h_i - \hat{h}_i\right)^2}{(n-p)\sum_{i=1}^{n}\left(h_i - \bar{h}\right)^2} \quad (4)$$

where $\bar{h}$ is mean of the observed height, and other symbols are the same as above.

5. *Homogeneousness and independence of residuals*: The residuals with predicted height, $\hat{h}_i$ and observed height, h_i were plotted against the predicted heights and examined.

6. *Biological realism*: The curves generated with models were checked with respect to their biological realism, for example, height curves against dbh were assumed to demonstrate an approximately a sigmoid shape with clear inflection point (culmination of height growth) that occurred in an early stage and other height increment should be more than zero.

The validation of models with splitting data set was not considered in this study. Because, splitting a data set into two parts: one for calibration and the other for validation cannot be independent as they have

Table 3 : Model parameter estimates and fit statistics (n = 644)

Models	Parameter estimates			Fit statistics		
	a	b	c	AIC	RMSE (m)	R^2_{adj}
M1	1.8182	0.722		1273	2.68	0.8321
M2	37.6799	-16.2513		1292	2.72	0.8265
M3	4.6453	-6.4669	-0.4156	1236	2.60	0.8420
M4	-0.3450*	0.9876	-0.0083	1216	2.56	0.8457
M5	2.0498	0.7682	0.0183	1231	2.59	0.8430
M6	0.7793	1.073	-0.0031	1221	2.57	0.8453
M7	46.104	13.638		1236	2.60	0.8421
M8	1.2479	1.6736	0.022	1111	2.36	0.8559
M9	35.032	0.0374	1.2075	1226	2.58	0.8445
M10	26.5123	0.0976		1352	2.85	0.8095
M11	28.2951	6.5214	0.106	1231	2.59	0.8432
M12	33.5721	0.0205	1.157	1221	2.57	0.8447

*non-significant (p> 0.05)

identical statistical structures (Yang *et al.*, 2004). The validation with splitting data does not provide any additional information as compared to respective goodness of fit statistics obtained directly from models with entire data set (Kozak and Kozak, 2003). Validating models with independent data would be the best alternative. But, it was not possible to get those data due to resource limitations.

Results and discussion

Except one with model M4, all parameter estimates of the models were significant ($p<0.05$). Except M1, M2 and M10, other models described more than 84% ($R^2_{adj}> 0.84$) of height variability (Table 3). The model M8 showed the best fits (smallest AIC and RMSE, and largest R^2_{adj}) followed by model M4. However, M4 was excluded from further analysis because one of its parameter estimates was non-significant ($p>0.05$). Also, M1, M2 and M10 were excluded because they demonstrated relatively poorer fit statistics.

Other remaining models showed almost identical fit statistics (Table 3). To identify the best model, graphical examination of fitted curves overlaid on observed data (Figure 1), height increment curves and residual plots (Figure 2) was performed.

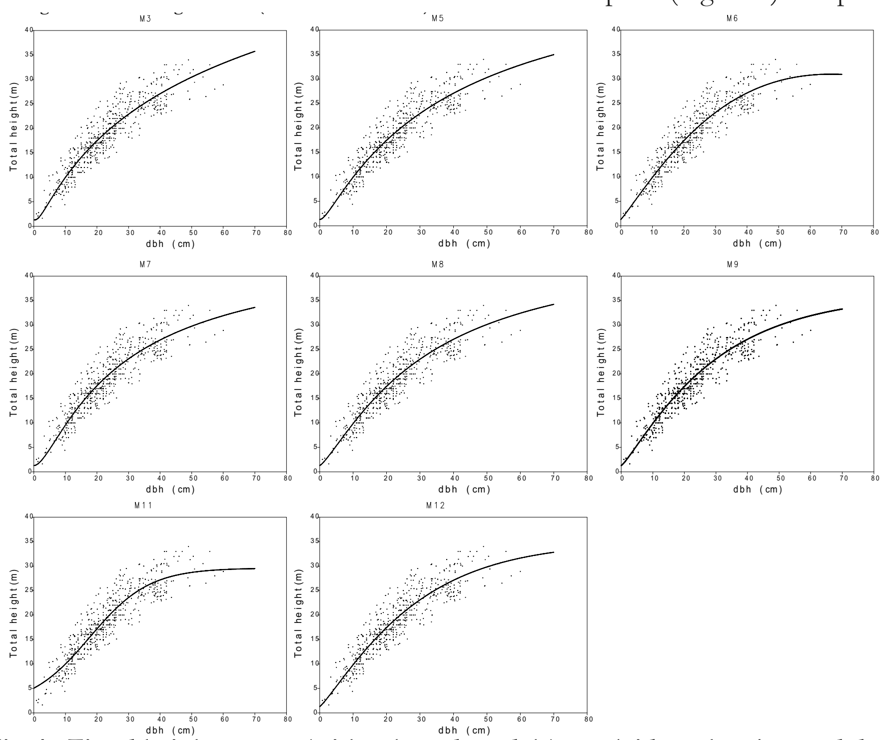

Fig. 1 : Fitted height curves (with selected models) overlaid on the observed data

The height curves generated with models M6 and M11 appeared to be biologically less relevant as they indicated almost leveling-off trends against dbh even within the observed data range where such trends were not visible. Also, M11 showed biologically illogical behaviour as its predicted heights at zero was more than 1.3 m. Therefore, both M6 and M11 were excluded from further examination. The biological logics rather than attractive fit statistics of the model should be important for biological such as height growth models (e.g. Vanclay and Skovsgaard, 1997; Ratkowsky, 1990; Schabenberger and Pierce; 2002) The height curves generated with models M5, M7, M8, M9 and M12 appeared to be identical up to 50 cm dbh. These models revealed biologically logical growth trends; for example, in early stage, height growth rate (change of height with respect to dbh) increased up to a certain dbh limit, but at the later stage it declined with increasing dbh (Figure 2, top). In the later stage, diameter growth should be faster than height growth because that a tree needs more strength to firmly withstand itself against external forces like wind blow by the thickening of its bole as tree grows to bigger and taller sizes (Khanna and Chaturvedi; 1994; Cato *et al.*, 2006).

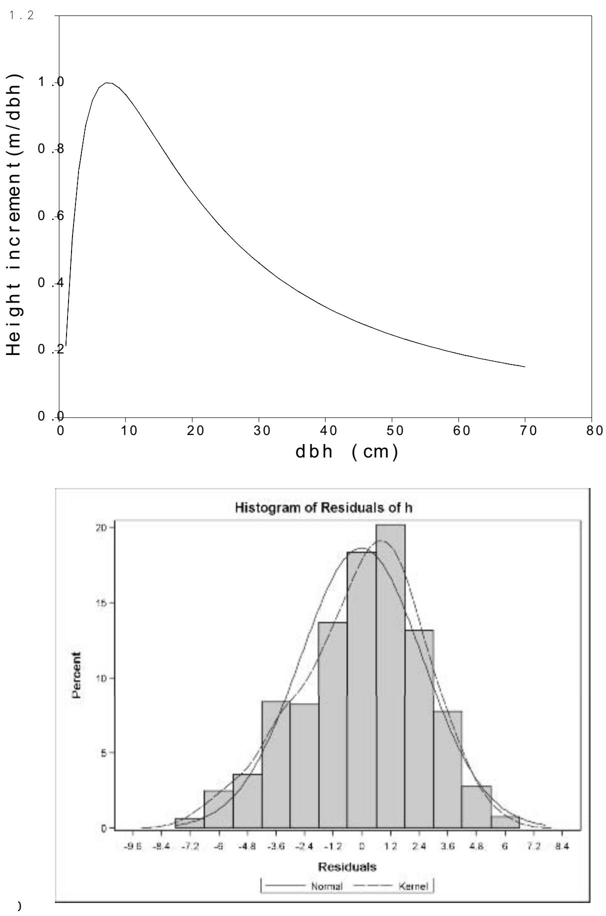

Fig. 2 : Height increment curve (top), and histogram of height residuals (bottom) with M8

Most of the residuals were found within 95% confidence limits, and the residual histogram looked bell-shaped with symmetrical (normal) distributions (Figure 2, bottom). Thus, this hinted that there was no substantial heteroscedasticity problem with the promising models.

There was different predicting performance with five different models beyond observed data range (Figure 3). Above 50cm dbh, predicted height with model M5 is the largest, followed by models M8, M7, M9 and M12. Due to lack of independent test data, it was not possible to identify the best model that could be used for extrapolation. The most appropriate way to check a model's predictive performance beyond range of calibration data is to test it against independent data from different tree populations over the widest possible range of size, site and stand conditions (e.g. Vanclay, 1994; Vanclay and Skovsgaard, 1997; Kozak and Kozak, 2003; Yang *et al.*, 2004). Validation of these models with independent data has been left to future forest modelers.

The model M8, which described the data in the best way, can be used for the prediction of total heights only within observed data range (Table 1). The heights not described by the models may be due to the absence of input variables like stand density (basal area or stem numbers) and site quality (site index) into the models. It is because stand attributes substantially affect height-diameter relationship (Calama and Montero, 2004; Sharma and Zhang, 2004; Tremesgen and Gadow, 2000; Sharma and Portan, 2007; Newton and Amponsah, 2007). More accurate and comprehensive height-diameter models would be possible where stand attributes are incorporated into the models.

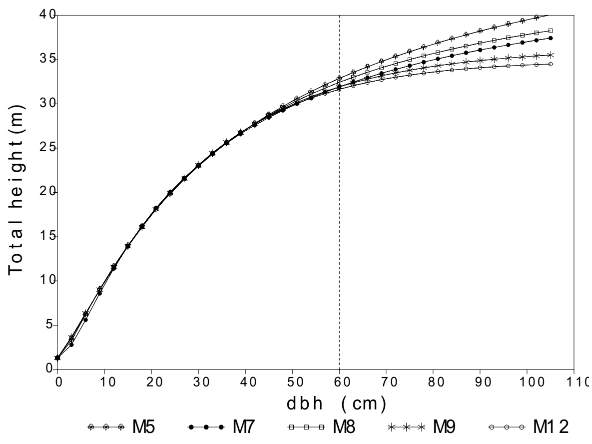

Fig. 3 : Height curves beyond observed data range

Conclusion

Among the twelve models, Hossfeld's model (M8) demonstrated the best fit and accounted for the greatest proportion of total height variations (R^2_{adj} = 86%). The model was mathematically flexible and biologically robust. The model's update through re-calibration and validation against independent data from widest possible ranges of size, site and stand conditions including stand attributes across the country would be important tasks for the future.

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Above-ground carbon stock assessment in different forest types of Nepal

S.K. Baral[1], R. Malla[1] and S. Ranabhat[2]

This study assessed the above-ground carbon stock in the five major forest types, representing two physiographic regions and four districts of Nepal. Altogether, 116 circular sample plots were laid out systematically in different forests types to inventory the forest. Total above-ground biomass was derived with allometric equations. Results indicated variation in age of the stand (18-75 years), above-ground carbon stock per hectare (34.30-97.86 dry wt. ton ha^{-1}) and rate of carbon sequestration (1.30-3.21 t $ha^{-1}yr^{-1}$), according to different forest types. The rate of carbon sequestration by different forest types depended on the growing nature of the forest stands. Tropical riverine and *Alnus nepalensis* forest types demonstrated the highest carbon sequestration rates in Nepal.

Key Words: Above-ground biomass, carbon, forest types, Nepal

Globally, forests act as a natural storage for carbon, contributing approximately 80% of terrestrial above-ground, and 40% of terrestrial below-ground biomass carbon storage (Kirschbaum, 1996). They play a critical role in reducing ambient CO_2 levels, by sequestering atmospheric C into the growth of woody biomass through the process of photosynthesis and also by increasing the soil organic carbon (SOC) content (Brown and Pearce, 1994). Carbon sequestration from atmosphere can be advantageous from both environmental and socioeconomic perspectives. The environmental perspective includes the removal of CO_2 from the atmosphere, the improvement of soil quality, and the increase in biodiversity (Batjes and Sombroek, 1997); while socioeconomic benefits include increased yields (Sombroek *et al.*, 1993) and monetary incomes from potential carbon trading schemes (McDowell, 2002).

The Kyoto Protocol recognized the importance of forest in mitigating the greenhouse gas emission (i.e. carbon dioxide, methane and other compounds) and has included forest and soil C sequestration in the list of acceptable offsets (UNFCCC, 1997). Thus, reducing emission from deforestation and forest degradation has emerged as an incentive mechanism for developing countries. However, updated national forest inventory data and technical capacity is poor; and accounting of changes in forest cover biomass stock, carbon emission and carbon removal are limited in the developing countries like Nepal (Dangi and Acharya, 2009). Therefore, this study has endeavoured to assess the above-ground carbon stock in the different forest types of Nepal.

Materials and methods

Study area

The study was conducted in five major forest types of four districts representing two physiographic regions of Nepal (Table 1). Chitwan district includes both Terai and Mahabharat foothills while Lalitpur, Kavre and Kaski districts represent the mid-hills region of Nepal.

Sample plots

There were 32, 34, 16, 16 and 18 number of sample plots employed in Tropical riverine, Hill Sal, Pine, *Schima Castanopsis* and *Alnus nepalensis* forests, respectively to inventory the forest. The plots were circular in shape, and the sizes varied as follows: trees (Size = 500 m^2), poles (Size = 100 m^2) and saplings (Size = 25 m^2). Field measurement was done by systematic sampling. Diameter at breast height (1.3 m from the ground level) was measured with diameter tape and tree height was measured with the Sunto Clinometer.

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Table 1 : District and geographical region wise distribution of studied forest types

S.N.	Forest type	District	Name of CF	Geographical Region	Major Species
1	Tropical riverine	Chitwan	Kumrose CF	Terai	*Terminalia tomentosa, Trewia nudiflora*
2	Hill Sal *(Shorea robusta)*	Chitwan	Amritdharapani CF	Mahabharat Foothills	*Shorea robusta*
3	Pine	Lalitpur	Saraswati CF	Midhills	*Pinus roxburghii, Pinus wallichiana*
4	*Schima-Castanopsis*	Kavre	Gaukhureshwar CF	Midhills	*Schima-Castanopsis*
5	*Alnus nepalensis*	Kaski	Andherikhola CF	Midhills	*Alnus nepalensis*

Equations used for biomass calculation

Total above-ground biomass (AGB) of hill community forests was calculated using different biomass equations produced by TISC (2000) according to the forest type and the species. Fresh weight of biomass was converted to dry weight using conversion factor of FORESC (1996). Similarly, the AGB of CFs located in the Terai was calculated using the Brown (1989) equation recommended for broadleaved species in tropical humid regions with precipitation from 1500 to 4000 mm and DBH limits from 5 to 130 cm, i.e.:

$$AGB = e^{[-3.141+0.9719*Ln(DBH*DBH*H)]} \quad ......1$$

Where,

AGB = Dry wt. of above-ground biomass (kg)

DBH = Diameter at breast height (cm).

H = Height of the tree (m).

Accuracy calculation of biomass measurement

Accuracy of biomass measurement was calculated using equation (2) and accuracy percentage was calculated using equation (3) and presented in Table 4.

$$\text{Accuracy (Bj)} = \bar{B} - \mu = t.\ Sx/\sqrt{n} \quad ....2$$

T = t value at infinity (1.96)

Sx = Standard deviation

n = number of plots

$\bar{B}$ = mean biomass

$$\text{Accuracy (Bj) Percentage} = Bj/\bar{B} *100 \quad ....3$$

Results and discussion

Majority of pole size stands were found in Hill Sal, *Schima-Castanopsis* and Tropical riverine forests. While in *Pine* and *Alnus nepalensis* forest, both tree size and pole size stands were found more or less same (Table 2).

Variation in age of the stand ranged from 18-75 years, variation in above-ground carbon per hectare from 34.70-97.86 ton ha^{-1} and variation in rate of carbon sequestration from 1.30-3.21 ton $ha^{-1}year^{-1}$ in different types of forests (Table 3).

Table 2 : Maximum, mean and mode value of height and dbh of forest types

S.N.	Forest type	Max ht (m)	Mean ht (m)	Mode ht (m)	Max dbh (cm)	Mean dbh (cm)	Mode dbh (cm)
1	Tropical riverine	27.5	15.65	19	123	29.49	18.5
2	Hill Sal	30.0	12.75	9	89	19.56	13.9
3	Pine	26.0	18.10	19	46	31.17	30.0
4	*Schima-Castanopsis*	13.5	6.95	6	32	8.86	6.0
5	*Alnus nepalensis*	22.0	15.50	14	40	32.00	22.0

Table 3 : Above-ground carbon stock and carbon sequestration rate of different forest types of Nepal

S.N.	Forest types	Age of the stand (yr)	A.G Biomass Dry wt (ton ha^{-1})	Total AG carbon stock (ton ha^{-1})	AG Rate of carbon sequestration (ton ha^{-1} $year^{-1}$)	Accuracy of biomass estimation (%)
1	Tropical riverine forest	25	178.83	80.47	3.21	17.65
2	Hill Sal forest	75	217.47	97.86	1.30	19.20
3	Pine forest	28	86.02	38.70	1.35	16.14
4	*Schima-Castanopsis*	22	76.24	34.30	1.56	11.27
5	*Alnus nepalensis*	18	76.00	34.60	1.92	14.56

Age of the forest types varied from 18-75 years and above-ground biomass varied from 76 ton ha^{-1} to 217 ton ha^{-1}. Above-ground biomass (ton ha^{-1}) was found to be highest in Hill Sal forest and lowest in *Alnus nepalensis* forest (Fig. 1). The figure shows that the age of all forest types except hill Sal was more or less same but above-ground biomass was different. This was due to slow and fast growing nature of the studied forest types.

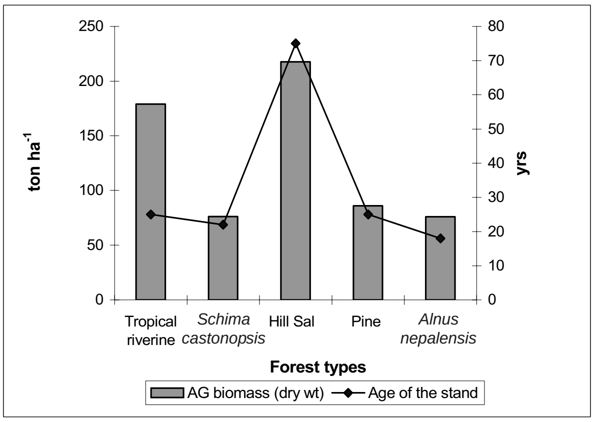

Fig. 1 : Relationship between Age and AG biomass of the different forest stands

Mean dbh of the forest types varied from 8.86-32.00 cm and age varied from 18-75 years (Fig. 2). From the figure, it is clear that tropical riverine, Pine and *Alnus nepalensis* have higher mean dbh against age of the stands as compared to *Schima Castanopsis* and Hill sal forest. This indicates that above three forest types are fast growing in nature than the other two.

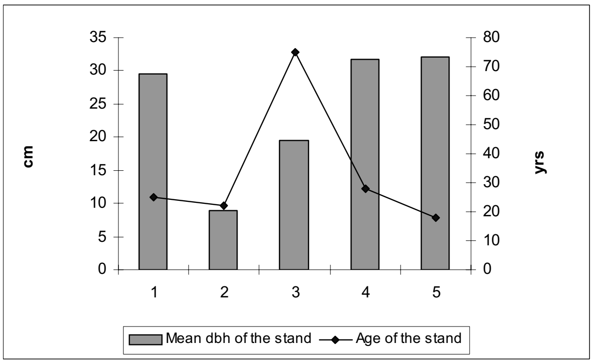

Fig. 2: Relationship between Age and Mean dbh of the different forest stands.

Note: 1 = Tropical riverine, 2 = *Schima-Castanopsis,* 3 = Hill Sal, 4 = Pine, 5 = *Alnus nepalensis*

Above-ground biomass per hectare was found to be highest in Hill Sal forest and lowest in *Alnus nepalensis* forest although their mean dbh were 19.56 cm and 32.00 cm respectively (Fig. 3).

From the figure, it can be clearly noticed that although the mean dbh of tropical riverine, *Pine* and *Alnus nepalensis* forest were more or less same, the above-ground biomass (ton ha^{-1}) of these forests were different. This was due to variation in density of stands per plot, site quality and growing nature of the stand (i.e. tapering).

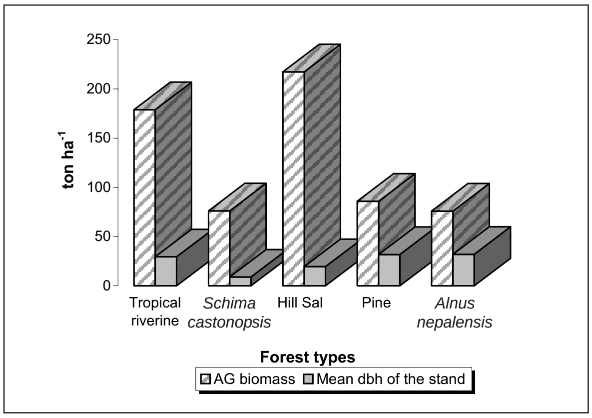

Fig. 3 : Above-ground biomass of different forest stands

The above-ground carbon stock of Hill Sal forest and Riverine forest were found to be higher i.e. 97.86 and 80.47 ton ha^{-1}, respectively whereas the above-ground carbon of *Schima-Castanopsis*, Pine amd *Alnus nepalensis* forests was lower i.e. 34.3, 38.7 and 34.6 ton ha^{-1} respectively (Fig. 4). The carbon stock ha^{-1} for Terai forest (80.47 ton ha^{-1}) and Hill forest (35.86 ton ha^{-1}) was more or less same as reported by Oli and Shrestha (2009) for Terai forest (76 ton ha^{-1}) and Hill forest (37 ton ha^{-1}).

Both Hill Sal and Riverine forests lie in Terai region of Nepal and are considered as "Tropical forest". Remaining three forests types represent Mid-hill region and are considered as "Sub tropical forest". The results show that "Tropical forests" had higher level of above-ground carbon stock than "Sub tropical forests".

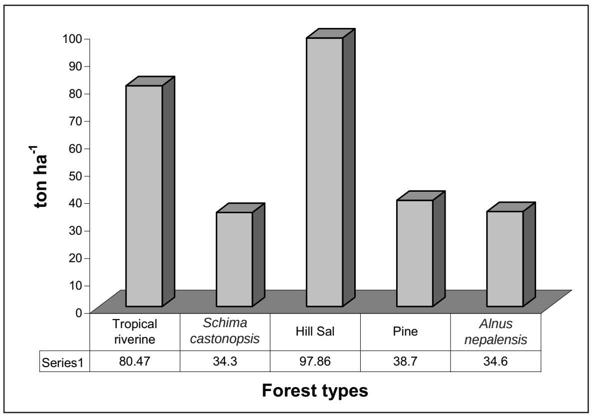

Fig. 4 : Above-ground carbon stock in different forest stands

Above-ground carbon sequestration rate of tropical riverine forest was found to be highest (i.e. 3.21 ton $ha^{-1}yr^{-1}$ (Fig. 5). Gorte (2009) also reported that Moist tropical forests are important for carbon sequestration, because they typically had high carbon contents. Tropical riverine forest, Pine and *Alnus nepalensis* are fast growing species thus had higher carbon sequestration rates while *Shorea robusta*, *Schima-Castanopsis* were slow growing species, thus had lower rates of carbon sequestration.

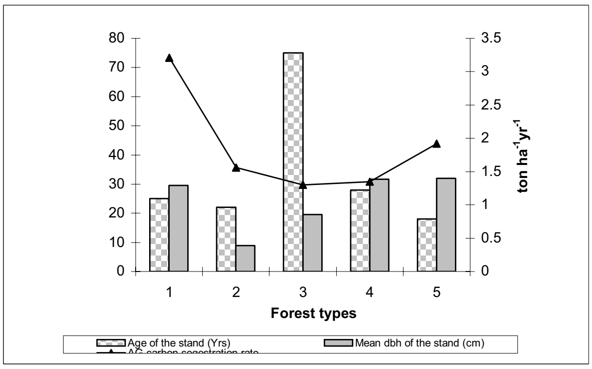

Fig. 5 : Age, Mean dbh and carbon sequestration rate of different forest stands

Note: 1 = Tropical riverine, 2 = *Schima-Castanopsis*, 3 = Hill Sal, 4 =Pine, 5 = *Alnus nepalensis*

Rana *et al.* 1989 reported carbon sequestration rate of Chir pine forests in the Central Himalayan Region ranged from 4.5 to 8.4 t C/$ha^{-1}year^{-1}$. However, this study suggested only 1.35 t C $ha^{-1}year^{-1}$ which was much lower (Fig. 5) than reported. This might be due to inappropriate site for planted pine forest. The result of this study was also supported by Jina *et. al,* 2008 who estimated carbon sequestration rate in degraded Pine forest, ranging from 1.01-1.27 ton $ha^{-1}yr^{-1}$. Mean carbon sequestration rate of five forest types was found to be 1.86 t C $ha^{-1}year^{-1}$ which seems logical and similar to the findings of Dhital (2009) i.e. 1.88 t C $ha^{-1}year^{-1}$ under normal management condition in the Community Forests (CFs) of Nepal.

Table 4 compares the findings of the study conducted at different time. It shows that carbon stock and carbon sequestration rate varied according to forest types.

Conclusions

There was considerable variation in the above-ground carbon stock and rate of carbon sequestration rate according to forest types and its geographical location. Forests representing the Terai region of Nepal had high above-ground carbon stock per hectare compared to hilly region. However, carbon sequestration rate of forest types depended on growing nature of the forest stands. Tropical riverine, Pine and *Alnus nepalensis* forests are important for carbon sequestration in tree biomass in Nepal, as seen from the comparatively higher carbon accumulation rates.

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Table 4 : Carbon sequestration potential of different forest types

Forest type	Carbon stock ($t\ ha^{-1}$)	Carbon séquestration rate ($t\ ha^{-1}yr^{-1}$)	Reference
All Central Himalayan Forests	250.00-300.00	6.00-8.00	Singh and Singh, 1985,1992
Seven Central Himalayan Forests	166.80-440.10	6.83-7.42	Rana et al, 1989
Temperate forest of the world	125.00	4.19	Malhi, 1998, Press et al 2000
Chirpine degraded forest		1.07-1.27	Jina et al, 2008
Oak degraded forest		1.47-1.84	Jina et al, 2008
Pine forest	38.70	1.35	This study
Tropical Riverine forest	80.47	3.21	This study
Hill Sal forest	97.86	1.30	This study
Alnus nepalensis forest	34.60	1.92	This study
Schima Castanopsis forest	34.30	1.56	This study
Average	57.18	1.86	This study

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Change assessment of forest cover in Ghodaghodi lake area in Kailali district of Nepal

S. Khanal[1]

Ghodaghodi Lake in Far-West Nepal has been listed as a Ramsar Site due to its significance as a habitat for several endangered species of flora and fauna. The wetland and its surrounding area is facing deforestation, forest degradation and encroachment. In this case study, unsupervised and finally supervised classification of multi-temporal Landsat imagery covering the wetland area was applied. A post-classification comparison approach was used to derive forest cover change maps. The results depicted the loss of forest cover over a thirty- one year period, in three time slices. The highest rate of loss was observed in the 1990 to1999 time slice.

Keywords: Change detection, forest cover, Ghodaghodi lake, Landsat

Land cover change detection and updating of land cover maps is a prerequisite to understand the land cover change dynamics and for the sustainable management of natural resources. Since wetlands are a critical habitat for diverse flora and fauna, including endangered species, understanding of landuse dynamics would be useful for devising effective conservation and management activities. Change detection, which encompasses identification of differences in the state of real-world entities or phenomena under consideration at different times, can be performed by comparing multi-date maps or remotely sensed images. Its capability for providing synoptic coverage and the repeatability of the provided data makes earth remote sensing a cost effective (Bauer *et al.,* 2003) and widely used method for change monitoring (Lu *et al.,* 2004). The present study used multi-temporal remotely-sensed data for forest cover change detection in the Ghodaghodi lake area of Nepal.

Materials and methods

Study Area

Ghodaghodi lake area is situated in the Kailali District of Far-West Nepal. It is the largest inter-connected natural lake system of the Terai Region. It lies along the Mahendra Highway at 28° 41' 03" N and 80° 56' 43" E at an altitude of 205 meters above sea level (DNPWC, 2005). The study area (27,460 hectare) encompasses three Village Development Committees (VDCs) of Kailali district namely Darakh, Sandepani and Ramshikharjhala (Fig. 1). The area was recognized as a significant wetland ecosystem supporting an appreciable assemblage of rare, vulnerable, and endangered species, and was designated as a Ramsar Site of International Importance under the Wetlands Convention in August, 2003 (Baral, 1992, Kafle, 2005). Though, the study area is outside the protected area system, its location between two protected areas and extensive forests along the Churia hills makes it an important corridor for wildlife as well as an important habitat for transient migratory species (Kafle, 2005).

Ghodaghodi Lake area was connected with the rest of the country by road only in 1993, following the completion of a bridge over the Karnali River. Since then, several anthropogenic activities that have become apparent around the lake area include: higher grazing pressure, illegal forest products extraction, deforestation and forest degradation, and encroachment (Bhandari, 2009; Diwakar *et al.,* 2009; Gurung, 2003; DNPWC, 2005, Kafle *et al.,* 2007). Like in other parts of the Western Terai, the area has also received human migrants from the mountain zone and experienced greater deforestation, expansion of settlements and cultivation in and around the wetlands (Sah and Heinen, 2001). Rampant deforestation and forest encroachment around the study area have been reported by MCN (2008). However, quantitative and synoptic assessments using standard methods such as remote sensing have been lacking.

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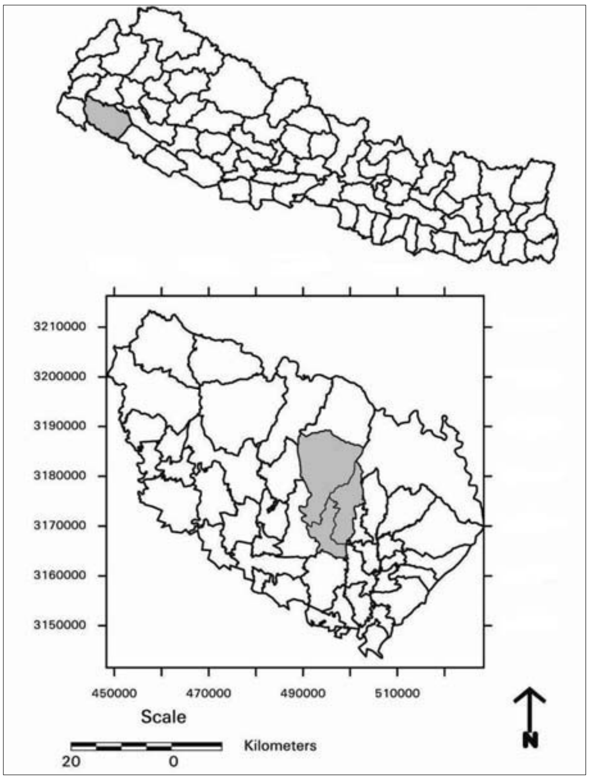

Fig. 1 : Location of Kailali district in Nepal and of the three VDCs of the study area in the district

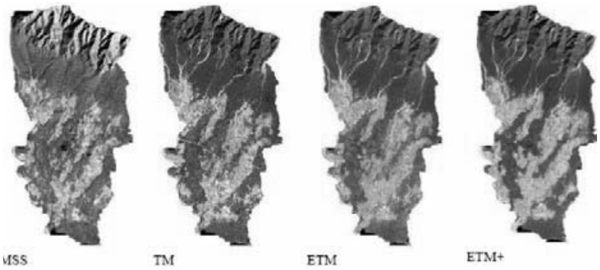

Fig. 2 : False Colour Composites (FCC) images of the study area of all dates used in this study

Data

Four Landsat images (Table 1) were downloaded from the United States Geological Service, (USGS) Glovis (http://glovis.usgs.gov) and GLCF (http://glcf.umiacs.umd.edu/) web sites on 12 December 2008 (Figure 2). Fortunately, the ETM+ scene that covered the study area was free from SLC-off defect. All scenes correspond to the peak of the growing season of vegetation, with 9 to 13 years in between acquisitions. High resolution satellite image of 2.5 m ALOS Pan-sharpened of November 2007, aerial photographs of the year 1964 and 1992, as well as 1:25.000 topo-sheets of the Nepal Survey Department were also acquired from the Department of Forest Research and Survey archives.

Image preprocessing

One of the important factors determining the accuracy of change detection is the precise geometric registration between multi-temporal images (Lu *et al.,* 2004). Histogram matching which converts the histogram of one image to resemble the histogram of another is useful for change detection (Erdas, 2008). The resampling of Multi Spectral Scanner (MSS) data to 30 m pixel was done using cubic convolution. The satellite image set was preprocessed through geometric correction and histogram matching to enhance those images. All images were geometrically corrected to the Everest 1830 datum using the rectified 2.5 m ALOS pan-sharpened imagery.

Image classification

Following unsupervised classification based on ISODATA Clustering, field verification and training data acquisition was conducted using five-class output. In the post classification, which is the supervised one based on maximum likelihood, inputs from the verification as well as other secondary maps and information were incorporated. Aerial photographs of the years 1964 and 1992 covering study area were scanned, geo-referenced with respect to imageries and used to aid classification of Landsat Thematic Mapper (TM) and MSS, respectively. Similarly, field data in addition to topo-sheets of Survey Department and November 2007 ALOS Pan-sharpened images aided classification of ETM and ETM+ images. This resulted in classified images each with two classes: forest and non forest. After completing classification of individual images, the majority, 3 x 3 filter was run on the classified image to remove the isolated pixels.

Table 1: Landsat dataset used

Sensor	Date	Path/Row	Source	Spatial Resolution (m)	Bands Used
ETM +	2008 Dec 03	144/040	Glovis	30	1,2,3,4
ETM	1999 Nov 09	144/040	GLCF	30	1,2,3,4
TM	1990 Oct 23	144/040	GLCF	30	1,2,3,4
MSS	1977 Jan 23	149/041	GLCF	57	4,5,6,7

Change detection

The post classification, change-detection technique of image differencing was applied on subsequent pairs of the classified single date images so that image difference data was obtained for the three time interval (Figure 3).

Accuracy assessment

Typical accuracy assessments involve verification of the randomly generated locations using reference data. For accuracy assessment, pixels in the classified image were compared to the reference pixels (Erdas, 2008). In this study two major factors undermined this. Firstly the datasets used were not recently acquired except for one. More importantly, there was a lack of reference data to compare the classification of earlier years. The aerial photographs, though distant in time to the image, were the only reference data available. For instance, the MSS image of 1977 was classified and evaluated using aerial photographs of 1964, with the assumption that forest cover change before highway construction was not significant. However, in case of 2008 ETM+, 50 randomly placed points were generated and compared with GPS data from field. This gave a classification accuracy of 96%.

Results and discussion

Figure 3 shows the result of the post-classification comparison for 3 pairs of images. The figures each represent spatial location of deforested area and forest/non-forest area in each data set. The positive change in forest area was observed to be negligible; and, therefore, those were included in the stable forest class.

The result suggests a decreasing trend for forest cover in the 3 VDCs of Kailali district (Figure 3). Forest cover, as a percent of total land cover, had decreased in the sequence of 75%, 70%, 65% and 64% for the years 1977, 1990, 1999 and 2008, respectively. The loss of forest cover was observed to be highest in the period between 1990 and 1999. The annual rate of change in this period is even higher, since this occurred over only a nine year period (Table 2). This trend supports the assumption that impact on forest intensified following the highway link. An almost equal area of forest was lost in the thirteen years between 1977 and 1990. On the other hand, the forest cover loss between 1999 and 2008 was remarkably less than other time frames. This may be due to the fact that, in earlier phases, the rampant

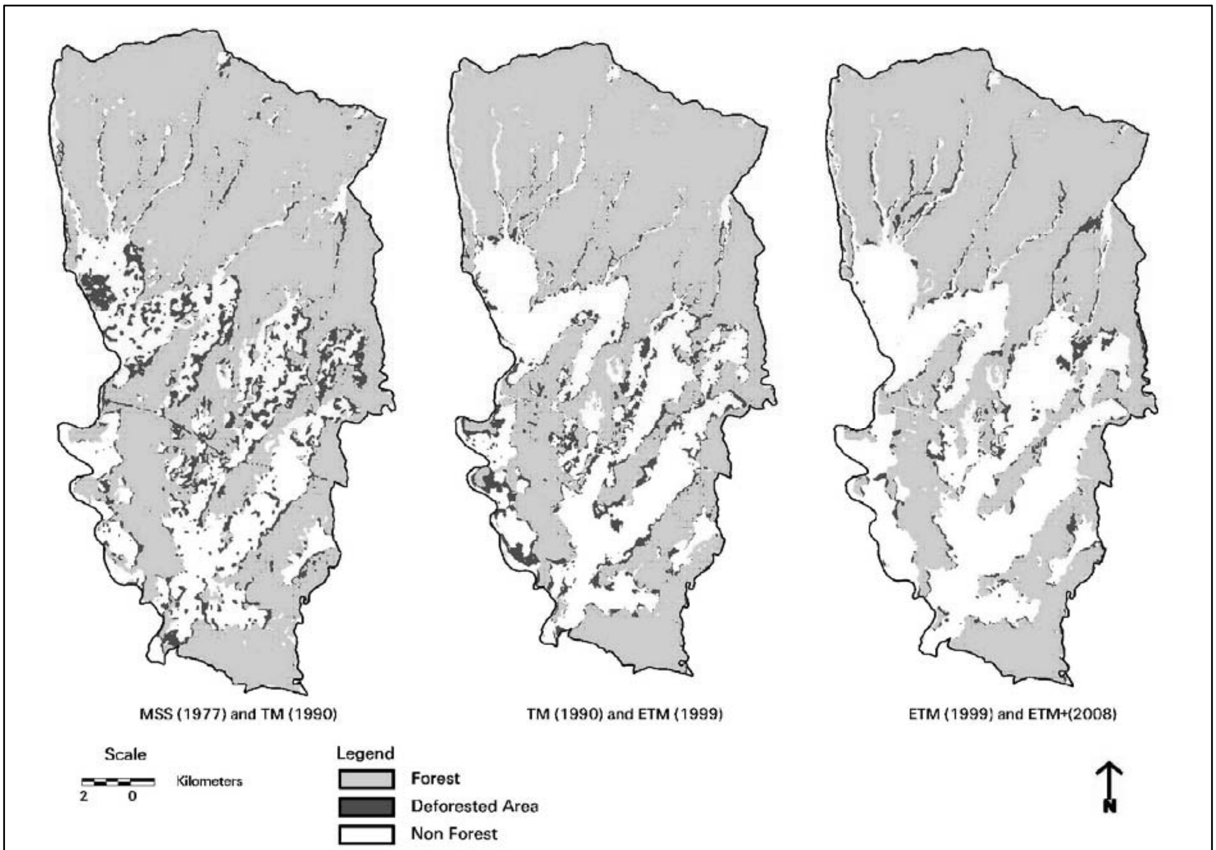

Fig. 3 : Map showing changed and remaining forest between consecutive images for 3 VDCs of Kailali district

land use change had already destroyed most of the accessible forests. Still, forest loss could be continuous in a very low sustained degree, due to illicit tree removal rather than rapid area clearance.

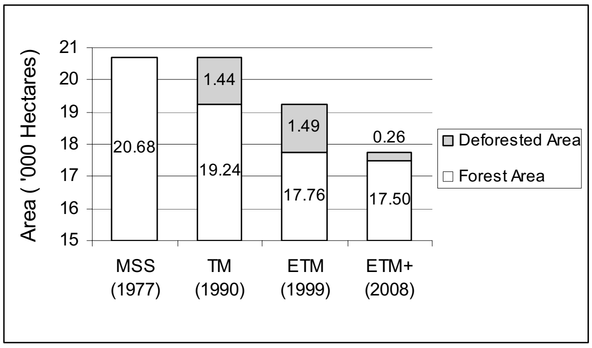

Fig. 4 : Total forest and deforested area in different time frame

The forest cover is shrinking particularly in the southern part of the study area while the hilly part of the north is almost intact with very low forest loss (see Fig 2). According to the observations made during the field visit, the significant portion of change in the north was due to the natural calamity of flood and landslide. In contrast, the southern plain has predominantly high value productive Sal (*Shorea robusta*) forest, high population density and the resulting activities of cultivation, forest encroachment and illicit tree cutting.

Image	Forest Area (% of total area)	Change (hectares)	Approx. Rate of Change (ha/year)
MSS	20683.9 (75.32)	-	-
TM	19244.8 (70.08)	1439.1	110.70
ETM	17758.1 (64.67)	1486.7	165.19
ETM+	17500.5 (63.73)	257.6	28.62

Table 2 : Multi-temporal forest areas, deforested areas and rates of change between 1977 to 2008

Conclusion

This study revealed that a very important wetland ecosystem in the western Terai of Nepal had lost significant forest cover from 1977 to 2008. Results indicated that forest cover decreased most intensely in the period between 1990 and 1999, following the construction of a major access road. However, the deforestation process, though low in intensity was still being sustained up to 2008. Since the integrity of wetland ecosystem and maintenance of forest cover are interlinked, it is crucial to prevent further forest loss and implement plantation and forest restoration activities.

Although from a very small study area, the results indicated that moderate to high resolution Landsat imagery were useful in landcover studies, for instance, in getting a time series of forest cover data sets. Forest cover change maps derived by classification of the imagery can provide information on the spatial distribution and amount of the change. Reasonably high accuracy can be attained when applied to recent image classification with sufficient reference samples. Knowledge of the detailed dynamics of multiple landuse categories can provide more clear understanding of the changes occurring. Therefore future research should seek to address this.

Acknowledgement

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Harvesting methods of *Cinnamomum tamala* leaves in private land: a case study from Udayapur district, Nepal

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Tejpat (*Cinnamomum tamala*) leaf is commercially one of the important non-timber forest products of Nepal. This paper attempts to elaborate and analyze the harvesting methods and techniques of Tejpat grown by the farmers in their private land. The study was conducted in the villages of Udayapur district where Tejpat was widely cultivated and harvested for income generation and trading purposes. Almost all farmers with private land had planted Tejpat. Complete lopping of leaves once a year was the exclusive practice for harvesting. The collection period for leaf was from Ashoj (October) to Magh (February) but the period for bark varied greatly, i.e. from Kartik to Poush (November to January) and Baisakh / Jestha (May / June). Bark collection was done only from old, dying, diseased and low leaf producing trees. Average number of trees per household ranged from 10 to 155. The mean diameter at breast height (DBH) of the trees was 39.58 cm. There was high positive correlation between the DBH and fresh weight of leaf. Fitting of linear regression of fresh weight of leaf with DBH proved that the relationship was statistically significant at 5% level of significance. The minimum age and size of trees for leaf harvesting were found to be five years and 16.18 cm, respectively.

Keywords: Fresh weight, harvesting, private land, Tejpat

Tejpat (*Cinnamomum tamala*, Buch.-Ham.) belongs to *Lauraceae* family and is widely distributed throughout South Asian countries. The tree is commercially known as Indian cassia. It grows wild in Nepal in between 450-2100 m elevation. It is commercially cultivated especially in Udaypur and Palpa districts (Bhattarai, 2001). It has been used in traditional medicines as an astringent, stimulant and carminative. The leaves of *C. tamala* have been used in Nepal for flavouring food and as medicinal ingredient. The leaves are used as a spice but can be employed with myrobalans during dyeing and in the manufacture of vinegar. It is also used as fodder. The essential oil from the leaves is also used as a flavouring agent. The components of Tejpat leaf oil were constituted of linalool (54.66%), a-pinene (9.67%), p-cymene (6.43%), B-pinene (4.45%), limonene (2.64%) and sixteen minor components less than 2% (Upadhaya *et al.*, 1994). The leaf oil is a rich source of eugenol (Krishnamurthy, 1996). The bark has been used as a substitute for true cinnamon, *Cinnamomum zelanicum* Breyn, which does not grow in Nepal (Jackson, 1994). Tejpat leaf and bark fall under low value products in Nepal, unlike Jatamansi, Chirayito, etc. (Amatya and Shrestha, 2003). Both wild and domesticated *cinnamomum* species fulfill subsistence requirements of many people especially for members of minority ethnic groups living in economically disadvantaged and physically remote locations of Nepal (Parajuli, 1997).

Tejpat is generally harvested in dry and mild weather from October to December and in some places, the collection is continued till the month of March (Upadhaya *et al.*, 1994). Tejpat leaves are 10-15 cm long, opposite with three veins running from the base to the apex and lanceolate with short blunt points. The leaves are collected once a year from young trees, and every other year from old and weak ones (Krishnamurthy, 1996). In harvesting the Tejpat leaf, the small branches are excised with the leaves and dried in the shade for 3-4 days. The leafy branches are then bundled for the market. On an average, 13 kg of dry leaves may be obtained from a tree but the quantity depends upon the local factors; a tree can yield from 8-20 kg of dry leaves in a year (TISC, 2003). According to Bhattarai (2001) a tree produces 10-25 kg of dry leaves and its 0.2-0.4% oil can be extracted from leaves. Timely collection of leaf is important since early and late collection may result in poor quality of the leaves or essential oil. Generally, leaves should be harvested before flowering. High rainfall

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reduces the aroma of leaves. Since the cultivation cost is modest, this is a profitable crop (Bhattarai, 2001). The price paid to the collectors has no relation to the wholesale price at the terminal market (Khatri, 1994). Edwards (1996) has documented Tejpat as an important non-timber forest product Nepal trades with India.

Although some studies have been carried out on Tejpat inventory and leaf/bark biomass for some districts, studies on scientific harvesting methods are lacking and systematic researches on this species have not been done. The purpose of the study was to explore and analyze the harvesting techniques of Tejpat leaf; and to relate the green weight of Tejpat leaf with different ages.

Materials and methods

The study was conducted on private forest lands and farmland plantation areas of Udayapur district in eastern Nepal. The forests in this district ranges from Terai to Mahabharat range. The forest types include tropical evergreen forest to Alder forest. More than 80% area is in high temperature zone. The rest of the areas has temperate climate. Most of this region are extremely sloped in the northern part of Churiya. Some of the district lies on plain lands. The study was confined to Betani, Huwas, Ranibas, Jyamirpakho, Jyamitar and Damling villages of Khabu VDC Ward No. 1, 2 and 8 of Udayapur district. The total number of respondents (both male and female) was 200, and the main ethnic groups represented of the study area were Magar, Rai, and Brahmin.

The existing traditional and advanced techniques of harvesting methods were identified by social survey. A set of questionnaires was used for interviews with farmers who had grown Tejpat trees on their private land and had been harvesting bark and leaf. After identifying the different harvesting techniques used by the farmers, a total of 42 trees with different ages were selected for the assessment of the existing harvesting methods by cutting and weighing of the leaves. Field work encompassed social survey, trees selection, diameter at breast height (DBH) and height measurement, harvesting of leaf and weight measurements. The records of all activities were documented carefully and precisely. The main variables measured were: number of trees per household (HH), DBH, fresh weight of leaf, and height of the trees. The height of the trees was estimated sunto-clinometer. Different groups of stakeholders such as primary producers/collectors, district cooperatives, community forest user groups, and the District Forest Office were consulted. Informal discussions with selected collectors at local markets, group discussion with Tejpat growing farmers, discussion with traders at the road head of Gaighat were done. The District Forest Office staff including concerned field Ranger and farmers were consulted for information relating to Tejpat cultivation and harvesting. They were mainly asked questions relating to their experience and traditional knowledge on leaf harvesting methods for high productivity and sustainability of the trees.

Results and discussion

Cultivation of Tejpat

Agriculture was the exclusive livelihood of the majority of the people in the area, although a few were involved in agriculture and shop keeping, and agriculture and labor. The family size ranged from 5 to 12 with an average of 8. Almost all farmers were found to have owned private land and cultivated Tejpat trees. The average number of trees per household was 72, ranging from minimum 10 to maximum 155 trees (Table 1). Most of the trees were of the age between 5-25 years. Regarding DBH and frequency of the trees, the DBH range of harvestable trees was 16.18 cm to 53.59 cm and their corresponding height was 5 m to 12 m, respectively. They were grown mainly on marginal lands, risers, and farmlands. Tejpat regeneration was from the seedlings collected from natural forest and then from self germination by seed dispersal from mother trees, but only a very few (about 10%) originated from nursery seedlings. The trees generally had not been planted but sprouted from the mother trees in the

Table 1 : An overview of Tejpat cultivation

Variable/particular	Mean	Std. Dev.	Minimum	Maximum
Family size	8	-	5	12
Trees/HH	72	-	10	155
Annual Income/ Tree/HH (NRs.)	1200	-	200	2500
DBH (cm)	39.58	10.08	16.18	53.39
Height (m)	8.17	1.72	5	12
Fresh weight of leaf (kg)	110.35	57.41	16	205

locality. Very few plantations had been done by collecting seedlings from natural forest of Tejpat or from nursery seedlings.

Growth and productivity

Table 2 : Tree size and leaf production

DBH class (cm)	No. of trees	Average fresh weight (kg)
10-20	2	18
20-30	7	40
30-40	10	82
40-50	16	128
50-60	7	190

The harvesting of Tejpat leaf and bark was dependent on the age and growth pattern of the trees. Although the range of the tree age was from one year seedling to 25-year old, the harvesting of leaves began at five years age. The average productivity per tree could be classified into three categories: 100 kg for 5-10 years old tree as low, 100-200 kg for 10-15 years as medium, and more than 200 kg for 15 years and older trees as good (kilogram was estimated from Bhari, 1 Bhari = approximately 35 kg of fresh leaf). The trees grouped into different DBH classes depicted that most of them were of 40 cm - 50 cm DBH (Table 2). The average fresh weight of leaves per tree for different DBH classes ranged from 18 kg to 190 kg. The trees grown by the farmers revealed moderate negative skewness and a mean DBH of 39.58 cm (Figure 1).

Biomass estimation

Correlation coefficients were calculated to find the degree of association between different variables. There were highly significant positive correlations between DBH, height and fresh weight of leaf (Table 3) and also high positive correlation between the height and fresh weight of leaves. The correlation was good enough to estimate the leaf biomass.

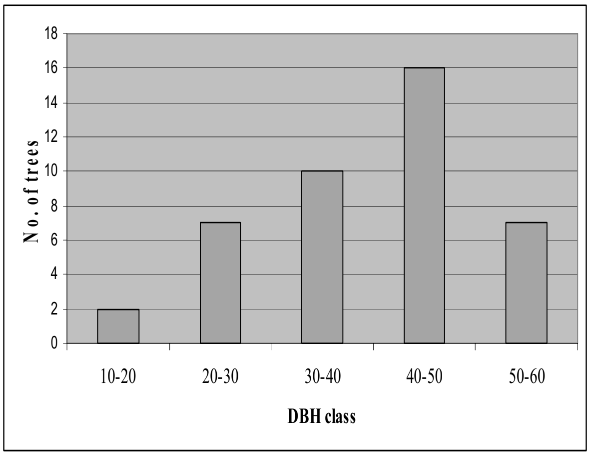

Fig. 1 : Frequency of trees according to DBH

Table 3: Correlation between different variables

Variable	DBH (cm)	Height (m)	Fresh weight of leaf (kg)
DBH (cm)	1.0000		
Height (m)	0.9123	1.0000	
Fresh weight of leaf (kg)	0.9021	0.8955	1.0000

A linear regression line was fitted for fresh weight of leaves and DBH class. The regression coefficient of explanatory variable (i.e. DBH) was statistically significant (t = 13.22, P>|t| = 0.000 at 5% level of significance, Table 4). The F-test indicated the variances between the two variables were significantly different.

Fitting a simple linear regression line by ordinary least square method (Figure 3), the estimated regression equation was:

Y = a + b DBH or Fresh weight (Y) = -92.98 + 5.14 DBH, where: a = constant, b = regression coefficient

The plotted data indicated that the deviation of the fresh weight values from the estimated line was higher for high DBH values of trees.

Table 4 : Fitting of regression for DBH and fresh weight of leaf

Fresh weight	Coefficient	Std. Err.	t-value	P>|t|	5% significance level, two tailed test
DBH	5.14	0.38	13.22	0.000	F (1, 40) = 174.75,
Constant	-92.98	15.86	-5.86	0.000	Prob. > F = 0.000, R^2 = 0.81

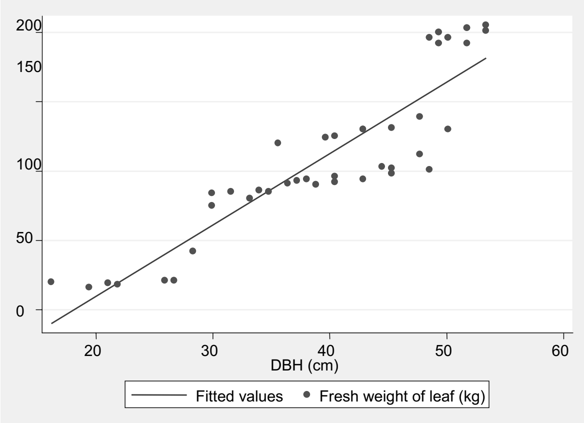

Fig. 2 : Linear regression between DBH and fresh weight of leaf

Harvesting and use

Both leaves and bark, called Dalchini, were harvested once a year. The collection period of leaves was from Ashoj (October) to Magh (February) for all farmers. However, the time of bark collection varied from Kartik-Poush (December–January), Baisakh-Jestha (May/June) according to the respondents. The reason for choosing May to June for bark collection was for assessing the sprouting of new leaves on lopped trees and to decide whether or not to debark if any leaves had sprouted up. Further, they revealed that the bark was collected from old, dying, diseased, and thinned trees and the trees producing few leaves. Factors such as age, DBH, and height of tree and leaf collection time were considered for leaf harvesting. Age and maturity were important considerations for bark collection. In most cases, handpicking was preferred for leaf collection because the tools could injure the trees. However, *Khukuri* was used for older branches. The entire foliage were harvested at one go. *Karda* (= knife) was a very common tool for debarking the tree from top to bottom as it was easy to debark from the top. Sometimes trees were felled and debarked. Leaf and bark were chiefly used as spice, cuisine flavor, fodder/ bedding for cattle, and for medicines. The small branches and debarked wood were used for fuelwood. Handpicking → drying → sale was the sequence. The products were purchased by local traders.

Existing problems and needs

Lack of scientific knowledge on cultivation and harvesting of Tejpat was the overriding problem. There were no training opportunities for the farmers. Other common problems included: leaf and bark diseases, storage problem of harvested products, no regular or systematic markets, dependency and monopoly of traders, and no availability of market in the vicinity. Other bottlenecks were low price, no processing, treatment and transport facilities, and cost ineffectiveness. Warm, dry room with limited ventilation and jute sack were needed for storage. Identification of suitable land for Tejpat cultivation was a serious anxiety for farmers.

The need for training to the farmers on Tejpat cultivation is urgent. There is a need for training to the farmers on treatment of disease, high productivity, information on processing, market structure, etc. Similarly, observation tours, trainings and other extension activities are equally important for introducing scientific management systems. Provision of modern harvesting tools, market facility in the vicinity, seed, fertilizer and treatments, and proper product pricing system with no monopoly could be some measures to tackle the problems. Market control for optimum pricing could be manipulated by the government. Effective initiatives from the government and concerned agencies are required for the promotion of Tejpat cultivation.

Conclusion

The study on harvesting methods of Tejpat leaf in private land of eastern Nepal has come to the following conclusions:

1. Almost all farmers who had private lands had planted Tejpat trees.
2. The complete lopping of leaves was once a year; bark collection only from old, dying, diseased and low leaf producing trees. The collection period for leaves was from October to February but for bark, it varied from December to January and May / June.
3. The average number of trees per household ranged from 10 to 155. The mean diameter at breast height (DBH) of the trees was 39.58 cm. The minimum age and size of trees for leaf harvesting were found to be five years and 16.18 cm respectively. The average fresh weight of leaves per tree for different DBH classes ranged from 18 kg to 190 kg.
4. There was positive correlation between the DBH and fresh weight of leaf. Fitting of linear regression between fresh weight of leaf and DBH showed that the estimate was statistically significant at 5% level of significance.

5. Some technical and financial supports are needed in that area to enhance the capacity of the farmers and local communities for Tejpat cultivation. There is a need for training to the farmers on treatment of disease, scientific harvesting/processing, high productivity, market structure.

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Modelling the growth of *Shorea robusta* using growth ring measurements

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This paper presents distance-independent diameter growth models for Sal (*Shorea robusta* Gaertn. f.) in Kankali Community Forest, Chainpur VDC, Chitwan. As the basis for modelling, stem discs were cut 0.3 m above-ground for a sample of 80 trees that had recently been felled. Growth rings were measured along four radii and, except for the outer part of a few discs originating from old trees, individual growth rings could be distinguished without major difficulty. Supplementary data were gathered as a basis for preparing models relating [i] diameter under bark to diameter on bark and [ii] diameter 0.3 m above-ground to diameter 1.3 m above-ground. Based on these data, auxiliary models were developed and used to convert growth ring measurements into diameter increment at breast height. The mean diameter increment was 0.87 cm/year (n = 1514) and the standard deviation was 0.33 cm/year. The relationships between diameter increment and current diameter, stem age, growth in previous years, rainfall and temperature were modelled. Four different models were presented. Rainfall during the growth season, particularly the months of May-July, proved to influence growth considerably and suggests a scope for dendroclimatological studies in Sal. .

Key words: Climate change, community forestry, diameter growth models, effect of rainfall, growth ring measurements

With respect to its silvicultural characteristics, Sal (*Shorea robusta* Gaertn. f.) has been described as 'the most gregarious and aggressive' tree species of the forest (Troup, 1921). Sal is a multipurpose species that can be used for timber as well as fuel and fodder and it is, therefore, considered a particularly important and attractive tree species (Jackson, 1994). In Nepal natural Sal forests have been highly acknowledged for their economic potential (Rautiainen and Suoheimo, 1997). However, despite the economic potential of Sal, few academic studies have been conducted on the growth of this species in Nepal.

As only a few forest growth models have been developed in Nepal, the uncertainty of growth and yield estimates is often high. In order to safeguard against depletion of resources, community forests apply conservative estimates of productivity and allowable cut. A possible consequence of this is that forests are underutilised and provide less income to communities than could have been obtained with reliable information about annual increment. Hence, the potential value of preparing growth models to communities is likely to be high.

The impact of global climate change on forest growth remains uncertain, both because the exact changes with regard to temperature and rainfall patterns are unknown and because the responses of forest ecosystems to long-term changes are poorly understood. It has been argued that increasing CO_2 concentrations in the atmosphere might lead to carbon fertilization but examples of decelerating growth, e.g. Feeley *et al.* (2007) indicate that temperature and rainfall patterns are often crucial. Particularly for a semi-deciduous/semi-evergreen species like Sal, growing in a region with distinct wet and dry seasons, growth is likely to be limited mainly by rainfall. Future growth will remain uncertain but at least the observed effects of past climate on growth can provide a clue to what changes to expect in the short-medium term.

Annual growth rings are useful to determine the age and growth rate of trees, and tree ring analysis is widely used to study the effect of climate on growth (Xiangding and Xuzhi, 1991). The old belief that annual growth rings are not formed in most tropical trees has been proven wrong for many species and during the past decade, studies on growth rings in

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tropical trees have been increasingly successful (Brienen and Zuidema, 2006; Worbes, 2002). Although not always easy to distinguish, Sal usually produces one growth ring per year, thereby enabling growth ring measurements to be made (e.g. Rautiainen 1999; Vanclay 1994).

The objective of this study is to develop local distance-independent diameter growth models for individual trees based on growth ring measurements. These models are meant for application in forest management planning. An additional objective is to prepare models including effects of past climate on diameter growth, thereby providing a basis for assessing likely short-term effects of climate change on growth. Finally, the paper aims to act as a source of inspiration for further study into local growth models for Sal.

Materials and methods

Study site

The study was conducted in Kankali Community Forest which is located in Chitwan District, approximately 16 km north of Bharatpur. The altitudinal range is 300-900 m, the total forest area is 760 ha and the main tree species is Sal.

Data collection

For a random sample of 80 stumps, a stem disc was cut 0.3 m above-ground (stump height). The discs were planed and sanded to enhance the visibility of growth rings. The growth rings were marked with a pencil and the radius from pith to each ring was measured along four perpendicular lines from pith to bark using a ruler (accuracy 1 mm). For each year, the four measured radii were averaged. The age of a stem was assumed equal to the number of growth rings counted. For young trees, an attempt was made to verify the age estimate by interviewing residents. In almost all cases the age estimates tallied with one another.

Growth was measured under bark but diameter is normally measured on bark, and it was therefore necessary to prepare the basis for a model relating diameters on and under bark. This was done by measuring diameter on and under bark for the 80 discs also used for growth measurements. For an additional random sample of 24 stumps, diameter measurements were carried out in the field using a girth tape (accuracy 1 mm). For the sample as a whole (n = 104) the minimum and maximum diameters on bark were 11.1 cm and 108.2 cm, respectively. Due to the relative scarcity of large stumps the mean diameter on bark was as low as 30.8 cm.

Growth ring measurements were conducted at stump height. To allow the estimation of growth at breast height, it was necessary to prepare the basis for modelling the relationship between diameters 0.3 m and 1.3 m above-ground. Therefore, a random sample of 176 trees was selected in various parts of the forest, representing different stand densities, slopes and aspects. For these trees the stem diameter was measured at both 0.3 m and 1.3 m above-ground using a tape measure (accuracy 1 mm). The minimum and maximum diameters at breast height (DBH) were 3.0 cm and 46.8 cm and the mean DBH was 17.5 cm.

For the period 1998-2007 monthly precipitation, and minimum and maximum temperature observed at the meteorological station at Rampur (27° 37' N; 84° 25' E), approximately 25 km to the southwest of the Kankali forest were obtained from the Department of Hydrology and Meteorology (DHM), Government of Nepal (Figure 1). The mean annual rainfall recorded was 2298 mm (range 1736-2694 mm).

The overall diameter distribution of Sal in the Kankali forest was obtained from ComForM, a collaboration project between Institute of Forestry in Pokhara and Hetauda, Department of Forest Research and Survey, Forest and Landscape Denmark and several associated partners that had established permanent sample plots in the forest (Meilby *et al.*, 2006).

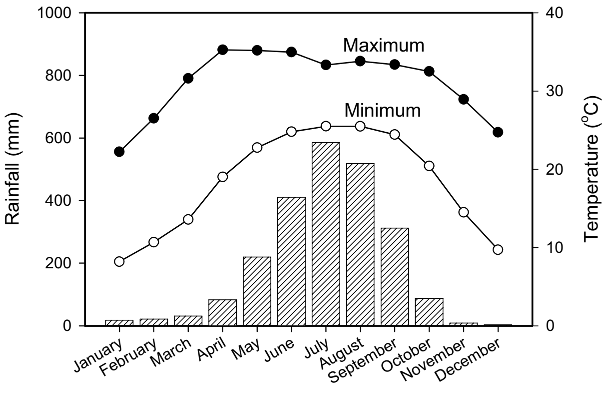

Fig 1 : Climate at Rampur approximately 25 km from Kankali (1998-2007): Mean monthly rainfall and mean monthly maximum and minimum temperatures. Data provided by the Department of Hydrology and Meteorology, Government of Nepal

Models

Auxiliary models

A total of 104 observations of stump diameter on bark and under bark were available for modelling. To describe the relationship between diameter under bark (d_{ub}) and diameter on bark (d_{ob}) the following regression models were tested:

$$d_{ob,i} = \alpha + \beta\, d_{ub,i} + \varepsilon_i \quad (1)$$

$$d_{ob,i} = \beta\, d_{ub,i}^{\gamma} + \varepsilon_i \quad (2)$$

$$d_{ob,i} = \alpha + \beta\, d_{ub,i}^{\gamma} + \varepsilon_i \quad (3)$$

where $i = 1\ldots104$, α, β, and γ are model parameters to be estimated, and the ε_is are random and normally distributed errors. Parameters were estimated using the NLIN procedure (non-linear model estimation) of the SAS v. 9.2 software package (Statistical Analysis System; SAS Institute, 2009a).

A total of 176 random trees were measured with regard to diameter at breast height and stump height (30 cm above-ground). The following model candidates were tested:

$$d_{1.3,i} = \alpha + \beta\, d_{0.3,i} + \varepsilon_i \quad (4)$$

$$d_{1.3,i} = \beta\, d_{0.3,i}^{\gamma} + \varepsilon_i \quad (5)$$

$$d_{1.3,i} = \alpha + \beta\, d_{0.3,i}^{\gamma} + \varepsilon_i \quad (6)$$

where $i = 1\ldots176$, $d_{1.3}$ and $d_{0.3}$ are stem diameters measured at breast height (1.3 m) and stump height (0.3 m), respectively, α, β, and γ are model parameters to be estimated, and the ε_is are random and normally distributed errors. Again parameters were estimated using the NLIN procedure.

Growth models

Based on the growth ring measurements, a total of 80 diameter growth series were available. These were used to parameterise a range of growth models where growth ($\Delta d_{i,t}$) in a given year (t) was described as a function of diameter ($d_{i,t}$) and disc age ($T_{i,t}$) before the growth season, diameter increment in the preceding growth season ($\Delta d_{i,t-1}$), rainfall (R_t), and minimum and maximum temperature. The models were developed from the two basic equations described by Zeide (1993): *increment* = $k \times size^p \times age^q$ and *increment* = $k \times size^p \times \exp(q \times age)$, where k, p and q are model parameters.

Model parameters were first estimated under the assumption that growth observations were independent. This was done using the NLIN procedure of the SAS software package. Next, models that performed particularly well were reformulated as mixed models including random, disc-specific effects. The parameters were estimated using the NLMIXED procedure (non-linear mixed model estimation) of the SAS v. 9.2 software package (SAS Institute, 2009b) and the following models were selected for further examination:

$$\Delta d_{i,t} = (\alpha + a_i)\, d_{i,t}^{\beta} \exp(-\gamma\, d_{i,t}) + \varepsilon_{i,t} \quad (7)$$

$$\Delta d_{i,t} = (\alpha + a_i)\, d_{i,t}^{\beta} \exp(-\gamma\, d_{i,t})\, T_{i,t}^{-\delta} + \varepsilon_{i,t} \quad (8)$$

$$\Delta d_{i,t} = (\alpha + a_i)\, d_{i,t}^{\beta} \exp(-\gamma\, d_{i,t})\, \Delta d_{i,t-1}^{\phi} + \varepsilon_{i,t} \quad (9)$$

$$\Delta d_{i,t} = (\alpha + a_i)\, d_{i,t}^{\beta}\, T_{i,t}^{-\delta} \exp(\lambda\, R_t) + \varepsilon_{i,t} \quad (10)$$

where the a_is are random and normally distributed disc effects ($i = 1\ldots80$), $a_i \sim N(0, \sigma_a^2)$, the $\varepsilon_{i,t}$ s are independently and normally distributed random errors, $\varepsilon_{i,t} \sim N(0, \sigma_\varepsilon^2)$, t is the year, and α, β, γ, δ, ϕ and λ are parameters to be estimated.

Results and discussion

Auxiliary models

The three models, (1)-(3), describing the relationship between diameter on and under bark all fitted the data very well with R^2 values of 0.998-0.999 (Table 1). Model (3) included three parameters and was thus the most flexible one. However, the power parameter, γ, could not be distinguished from 1 (Pr>|t| = 0.58) and, hence, there seemed to be no reason to prefer Model (3) over the linear Model (1), particularly as the Root Mean Squared Error (RMSE) of Model (1) was the lower one. Unfortunately, the dataset did not include stems with diameters of less than 8.4 cm under bark (11.1 cm on bark) and the estimated intercepts of Models (1) and (3) implied that the predicted diameter on bark of a stem with an under-bark diameter of 0 cm would be 2.5-2.7 cm. Since this is not in agreement with reality and since the model would be used to predict on-bark diameters for under-bark diameters considerably smaller than 8.4 cm, Model (2) was considered the best alternative.

Models (4)-(6) describing the relationship between on-bark diameter 0.3 m and 1.3 m above-ground all fitted the data very well with R^2 values of 0.992-0.993 (Table 1). In the three-parameter model (6), the intercept was not significantly different from zero

(Pr>|t| = 0.64) and the power parameter, γ, was statistically indistinguishable from 1 (Pr>|t| = 0.86). Therefore, Models (4) and (5) were preferred to Model (6). The linear Model (4) predicted a diameter of 0.25 cm at breast height for a diameter of 0 cm at stump height. Since this is not realistic, Model (5) was considered the most attractive alternative.

Diameter growth data

As a basis for modelling diameter growth at breast height, the original growth ring measurements 0.3 m above-ground were transformed using Models (2) and (5). Hence, denoting the average radius from pith to perimeter of a growth ring in year t by $\overline{r_t}$, the on-bark diameter at breast height (DBH) was estimated as:

$$d_{1.3,t} = \hat{\beta}_{(5)}\left[\hat{\beta}_{(2)}\left(2\overline{r}_t\right)^{\hat{\gamma}_{(2)}}\right]^{\hat{\gamma}_{(5)}}$$

where $\hat{\beta}_{(2)}$, $\hat{\beta}_{(5)}$, $\hat{\gamma}_{(2)}$ and $\hat{\gamma}_{(5)}$ are the estimated parameters of Models (2) and (5). Subsequently, annual diameter increment was estimated as $\Delta d_t = d_{1.3,t} - d_{1.3,t-1}$.

The majority of the sample trees were 10-20 cm DBH (84%) and 11-20 years of age (75%), and only 6.3% were larger than 50 cm DBH. Thus the composition of the sample clearly reflects that it is based on thinned trees. However, as all trees were once thinner than at the time of felling, the diameter increments and corresponding diameters before the growth season cover the diameter range up to 75 cm quite well (Figure 2). For the Kankali forest as a whole, ComForM estimated that as much as 81% of the Sal trees were less than 10 cm DBH and the estimated percentage of stems larger than 50 cm DBH was only 0.4%.

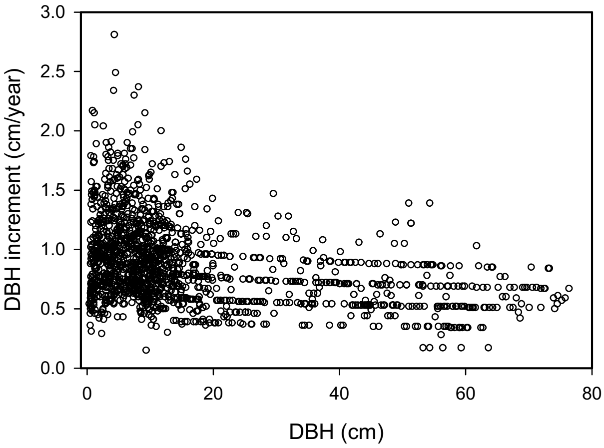

Fig. 2 : Diameter increment vs. diameter at breast height before the growth season

Effect of climate

Preliminary analysis showed that growth was only weakly correlated with whole-year climate variables. To identify the period of the year when weather had the greatest influence on growth, rainfall was totalled for periods of 3-6 months starting from March, April, May, June and July. Average maximum and minimum temperatures were calculated for the same periods. Coefficients of correlation between diameter increment and total rainfall, maximum and minimum temperature were estimated. It emerged that correlations between growth and minimum temperature generally were not significant at the 5% level. Therefore, they have not been included in Table 2.

Table 1 : Models describing the relationships between diameter on and under bark, (1)-(3), and between diameter at stump height and at breast height, (4)-(6). Standard errors are given in square brackets. Symbols: see text. Units of measurement: d_{ob}, d_{ub}, $d_{1.3}$, and $d_{0.3}$: cm

Model (structural part)		n	RMSE	Adj. R²	Parameter estimates		
					Par. α	Par. β	Par. γ
(1)	$d_{ob} = \alpha + \beta d_{ub}$	104	0.753	0.999	2.735 [0.111]	1.061 [0.0031]	n.a.
(2)	$d_{ob} = \beta d_{ub}^{\gamma}$	104	0.891	0.998	n.a.	1.534 [0.0232]	0.9219 [0.0037]
(3)	$d_{ob} = \alpha + \beta d_{ub}^{\gamma}$	104	0.756	0.999	2.541 [0.367]	1.093 [0.0592]	0.9935 [0.0116]
(4)	$d_{1.3} = \alpha + \beta d_{0.3}$	176	0.751	0.992	0.2502 [0.123]	0.8499 [0.0054]	n.a.
(5)	$d_{1.3} = \beta d_{0.3}^{\gamma}$	176	0.751	0.993	n.a.	0.8953 [0.0185]	0.9879 [0.0061]
(6)	$d_{1.3} = \alpha + \beta d_{0.3}^{\gamma}$	176	0.753	0.993	0.1838 [0.398]	0.8625 [0.0725]	0.9965 [0.0198]

The correlation between rainfall and growth was generally positive as expected, and it appears that to obtain a high coefficient of correlation the period for which rainfall is calculated must include the months of May, June and July. Thus, the highest coefficients of correlation were observed for three- and four-month periods starting on the 1st of May, a five-month period starting on the 1st of April, and a six-month period starting on the 1st of March (Table 2).

Correlations between maximum temperature and growth were generally negative, reflecting the fact that maximum temperature and rainfall were negatively correlated. For example, the coefficient of correlation between total rainfall and maximum temperature for the three-month period May-July was -0.653 ($Pr>|r| =0.041$, $n=10$). The coefficients of correlation between growth and maximum temperature were generally lower in absolute terms than those calculated for growth and rainfall, and in the growth models it was therefore decided to include rainfall for the period May-July. The average total rainfall (1998-2007) for this period was 1215 mm with a minimum of 623 mm and a maximum of 1846 mm.

Growth models

Diameter increment was negatively correlated with age ($r = -0.385$, $Pr>|r| < 0.0001$), negatively correlated with diameter before the growth season ($r = -0.370$, $Pr>|r| < 0.0001$), positively correlated with diameter increment in the preceding growth season ($r = 0.404$, $Pr>|r| < 0.0001$), and positively correlated with rainfall in May-July ($r = 0.215$, $Pr>|r| < 0.0001$).

Parameter estimates of the four growth models, (7)-(10), are shown in Table 3. The final parameter estimates of the structural part of Models (7) and (8) differed little from those estimated using ordinary non-linear least squares (Sapkota, 2008). All parameters were significant at the 5% level or better, and except for the negative parameter estimate of β in Model (9) the signs of the estimated parameters were as expected. Thus, in agreement with the observed correlation patterns, growth generally decreased with increasing age, increased with increasing growth in the preceding growth season, and increased with increasing rainfall. Models (7) and (8) showed that growth initially increased, culminated, and finally decreased with increasing diameter.

The estimated variances of the random disc effects, $s^2(a)$, corresponding to standard deviations of about 0.1, were low compared with the estimated values of the fixed effects, α, which ranged from 0.97 to 1.12. The estimated variances of the error terms, $s^2(\varepsilon)$, were similar for all four models (0.073-0.083) but since only part of the data can be used for Models (9) and (10) direct comparison of the models must be based on a reduced dataset. For the 769 observations that can be used in all four models, the standard deviation of the prediction errors was observed to decrease from 0.32 cm for Model (7) to 0.31 cm for Model (8) and 0.30 cm for Models (9) and (10).

The annual diameter increment predicted by Model (7) peaked at a diameter of only 4 cm and reached a maximum value of about 1 cm/year. Beyond the

Table 2 : Coefficients of correlation† between diameter growth, Δd , and climate variables (rainfall and maximum temperature) calculated for periods of 3-6 months starting from the 1st of March to July

	Period length	First month of the period considered				
		March	April	May	June	July
Rainfall	3 months	0.131***	0.160***	0.215***	0.188***	0.089*
	4 months	0.167***	0.208***	0.211***	0.149***	0.060NS
	5 months	0.208***	0.214***	0.179***	0.127***	0.065NS
	6 months	0.207***	0.176***	0.161***	0.131***	0.063NS
Max. Temp.	3 months	-0.080*	-0.126***	-0.147***	-0.080*	-0.035NS
	4 months	-0.100**	-0.134***	-0.181***	-0.067NS	0.020NS
	5 months	-0.097*	-0.183***	-0.150***	-0.019NS	0.043NS
	6 months	-0.113**	-0.156***	-0.114**	0.003NS	0.091*

† Levels of significance: 'NS': not significant, '*': p<0.05, '**': p<0.01, '***', p<0.001

maximum, the predicted diameter increment decreased slowly and at a diameter of 70 cm it was still 0.5 cm/year (Figure 3). Model (8) including stem age indicated that, particularly for young stems, the expected growth deviated considerably between stems that had reached a given diameter within comparatively few years and those for which it had taken a longer time. As size and age increased, the difference between the diameter increments predicted by Models (7) and (8) tended to decrease.

The minimum observed rainfall in the three-month period May-July (1998-2007) was 623 mm and the maximum was 1846 mm. The diameter increment predicted by Model (10) for a rainfall of 500 and 2000 mm is shown in Figure 4. It appears that growth was strongly influenced by rainfall but, like for Model (8), it is also seen that the expected growth depended very much on the time that it had taken for a stem to reach a given diameter.

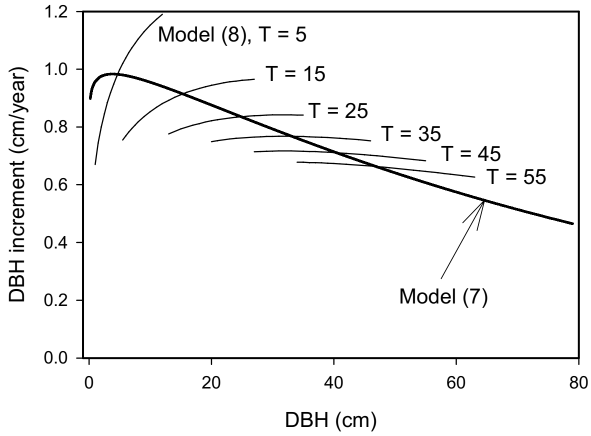

Fig. 3 : Diameter increment predicted by Models (7) and (8). For Model (8) growth predictions are shown at ages *T* = 5, 15, …, 55 years

Growth patterns

As expected, the diameter increment was strongly related to both diameter and age. But diameter and age were also strongly correlated and when variables such as diameter increment in the preceding year or rainfall during the growth season were included in a model, it therefore turned out that the decrease of growth after its culmination at diameters of 2-8 cm could either be modelled using diameter or age, but not both. The early culmination of growth may be related to the fact that in the Kankali forest most young stems presumably originated from root suckers.

All models include diameter at the beginning of the growth season. Therefore, the effects of stem age in Models (8) and (10) can be interpreted as effects of past growth success, reflecting differences between trees with regard to site conditions, competition and genetics. Similarly, in Model (9) the effect of diameter increment in the preceding growth season could be interpreted as an effect of past growth success in combination with weather conditions in the preceding year.

Growth and climate

The correlation between growth and climate variables describing average weather conditions within a year proved low. Higher correlations were obtained by considering the growth season only, estimating rainfall and average temperatures for periods of 3-6 months. Within the growth season, rainfall and maximum temperature were negatively correlated and while diameter growth was positively correlated with rainfall it was therefore negatively correlated with maximum

Table 3 : Diameter growth models. Approximate standard errors are given in square brackets. Symbols: see text. Units of measurement: *d*, Δd and Δd_{t-1} : centimetres, *T*: years from pith, *R*: metres of rainfall (total for the months of May, June and July)

			Estimates of fixed effects parameters							
Model (structural part)		n	Par. α	Par. β	Par. γ	Par. δ	Par. ϕ	Par. λ	$s^2(a)$	$s^2(\varepsilon)$
(7)	$\Delta d = \alpha\, d^{\beta} \exp(-\gamma\, d)$	1514	0.9680 [0.023]	0.0454 [0.013]	0.0118 [0.001]	n.a.	n.a.	n.a.	0.0151 [0.003]	0.0785 [0.003]
(8)	$\Delta d = \alpha\, d^{\beta} \exp(-\gamma\, d) T^{-\delta}$	1514	1.0496 [0.031]	0.2688 [0.056]	0.0084 [0.001]	0.2739 [0.066]	n.a.	n.a.	0.0102 [0.003]	0.0793 [0.003]
(9)	$\Delta d = \alpha\, d^{\beta} \exp(-\gamma\, d)\, \Delta d_{t-1}^{\phi}$	1436	1.1094 [0.032]	-0.0469 [0.018]	0.0051 [0.001]	n.a.	0.2228 [0.026]	n.a.	0.0105 [0.003]	0.0729 [0.003]
(10)	$\Delta d = \alpha\, d^{\beta}\, T^{-\delta} \exp(\lambda\, R)$	781	1.1206 [0.070]	0.2842 [0.072]	n.a.	0.4575 [0.076]	n.a.	0.1767 [0.035]	0.0093 [0.004]	0.0830 [0.004]

temperature. Irrespective of the duration of the period considered, the correlation between growth and minimum temperature remained very low.

Model (10) included rainfall for a three-month period from May to July and showed a clear positive relationship between rainfall and growth. Based on this model it may appear that if the observed average rainfall of about 1200 mm (May-July) was to be halved in the future, it would lead to a reduction of growth of about 10%. Similarly, it appears that if rainfall was to be doubled, the expected diameter growth would increase by about 24%. Unfortunately the climate series only covers 10 years and, although there is no doubt that long-term changes of precipitation would have considerably greater effect on growth than those predicted by Model (10), the available data do not allow describing such long-term changes.

Limitations

The models describing relationships between diameter under and on bark and between diameter 0.3 m and 1.3 m above-ground were prepared on the basis of static data and are therefore implicitly based on the assumption that the pattern observed for a cross-section of trees at a given point in time was identical to the one that might be observed for an individual tree over time.

Stem discs were cut from the stump of trees felled in the latest thinning. For middle-aged and old trees only limited numbers of thinned trees were available, and it was difficult to get a felling permit. Therefore, only few middle-aged and old trees were included in the sample. Potentially, this may be a source of error. In addition, since the sample trees were all trees that had been removed in thinning, there is no guarantee that the observed growth is representative of trees in the Kankali forest in general. However, as trees selected for thinning appeared to include both healthy and weakened trees it is uncertain to what extent this might lead to bias.

It is important to note that since the growth models do not take stand conditions into account, growth predictions will only remain unbiased to the extent that the basal area of the forest remains roughly unchanged. However, since its establishment as a community forest, the Kankali forest has been in transition from a degraded to a more well-stocked state and the basal area can still be expected to increase somewhat in the coming years. Hence, the models reported here must be considered preliminary and in the long term models taking stand basal area into account are needed.

It may be argued that it would have been possible to account for stand conditions by measuring basal area of the forest within some neighbourhood around the sample trees. Unfortunately, since the development of the surrounding trees and the likely removal of such trees in the past would not be known with certainty, it would be impossible to provide reliable estimates of past basal area for a period of more than a few years.

As can be seen in Figures 2-4, particularly for Model (7), there is a clear indication that most trees in the area started as root suckers that did not have an initial establishment period characterised by slow growth. Instead most stems grew fast from the outset.

It is important to note that the low number of large discs in the sample implies that growth predictions for large-diameter trees are uncertain. Growth ring measurements were generally observed to become more difficult with increasing age and diameter and the large discs that were included in the sample were those for which growth rings could actually be observed. In a few cases it was necessary to discard discs because rings could not be distinguished properly. Since narrow rings are likely to be more difficult to distinguish than wider ones, the growth of the selected sample discs might be greater than average. Consequently, the growth predicted by the models at large diameters may be biased.

Conclusion

For Sal in Kankali Community Forest, growth ring measurements proved comparatively easy for young trees. For older, slow-growing trees it was more difficult to distinguish the growth rings. In addition, only few large trees were included in the sample. This may imply that model predictions are not true for large trees.

Sample trees were selected among trees that had been felled in thinning and if the thinned trees are not representative of the population with regard to growth, this may imply that growth predictions are biased.

Diameter growth was influenced considerably by rainfall during the growth season. But including rainfall in months outside the period from April to

August merely obscured the relationship between growth and rainfall.

The observed significant relationship between climate variables and diameter increment in combination with the feasibility of growth ring measurements indicates that there may be scope for dendroclimatological studies in Sal.

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Value chain analysis of non-timber forest products in Baglung district, Nepal

A. Paudel[1], B. P. Subedi[2], S. Gyawali[2], G. K. Thapa[3], and M. B. Sharma[3]

This study was carried out in five Village Development Committees of Baglung district, Nepal. The main objective was to assess the constraints and opportunities to run the non-timber forest products based enterprises, and to design business solutions to make their value chains more efficient and competitive with the best utilization of the available resources. Primary data were collected through group discussions, key informants interview, informal meetings and direct observations, using open-ended questionnaires and checklists. Similarly, secondary data were gathered from reports and records of community forest user groups, District Forest Office and other organizations. The data were analyzed using qualitative and quantitative tools. The identified major constraints concerning the selected value chains are: absence of detailed resource inventory; inadequate knowledge and skills with local people about modern technology and product quality parameters, local resource management policy and sustainable resource harvesting; insufficient finance with local processors; lack of sufficient information about market; and poor infrastructure development. In addition, the study also identified a number of opportunities such as the resource potential and monetary benefits to the local people; financial access through community forest user groups' fund and financial institutions; growing market demand for quality products; involvement of service providers in forest resource management; and supportive policy for employment generation from locally available natural resources. This paper has suggested some business solutions for the effective value chain of selected products.

Key words: Business solution, constraints, non-timber forest products, opportunities, value chain

A value chain (VC) is a chain of value-creating activities which are not isolated from one another. Rather, one activity often affects the cost or performance of the others (www.netmba.com). It is a sequence of productive processes from the provision of specific inputs for a particular product to primary production, transformation, marketing and distribution, and final consumption (Amatya, 2009). The products pass through all activities of the chain in order, gaining value with each activity. The value chain analysis (VCA) examines the full range of activities that are required to bring a product in a particular enterprise from its conception to its end markets. A good VCA provides a snapshot of an enterprise at a particular time, while VC mapping indicates the way a product flows from raw material to end markets.

Most of the forest enterprises in developing countries are small and medium enterprises (SMEs) (Elson, 2009), and in many of them, especially those from South Asia, Non-timber forest products (NTFPs) have been identified as one of the potential, high value commodities (Amatya, 2009). More than 700 species have been recognized as NTFPs (Edwards, 1996), and more than 100 types of these are being used in medicinal, aromatic and other industrial preparations are being collected in Nepal for commercial purposes (Poudel, 2009). About 42 thousand tons of over 100 NTFPs are traded, generating over $30 million annually (Gurung, 2009).

NTFPs are relatively abundant in rural areas where other income generating opportunities are limited (USAID, 2006). In those areas, NTFPs-based SMEs offer good prospects for enhancing the livelihood and income of local communities (Subedi, 2006). However, the development of an enterprise fulfilling environmental, market and legal requirements can only be facilitated through VCA. To optimize

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enterprise contribution towards the improvement of livelihoods of poor users, who have been mostly raw material suppliers, would require the identification of bottlenecks in VC and deconstricting them.

In this study, NTFPs refer to the traded parts of plants other than timber, fuelwood and fodder, as per the definition of Master Plan for the Forestry Sector (1989). The study foci were: to identify and select major NTFPs in the study site; to classify major actors and their functions within the VCs; to identify potential service providers (SPs), and to design commercially viable business solutions. This paper describes the methodology of VCA and provides business solutions for efficient and effective VC of selected NTFPs from enterprise perspectives.

Materials and methods

Five Village Development Committees (VDCs) of Baglung district, namely Khunga, Adhikarichaur, Taman, Khunkhani and Bongadovan were selected for the study based on the availability of commercial NTFPs, ecological connectivity and community interest. They were selected through a district level workshop, participated by governmental and non-governmental organizations (GOs/NGOs) that have been involved in forestry-related activities within the district. Some of these were: the District Development Committee (DDC), the District Forest Office (DFO), the Federation of Community Forest Users, Nepal (FECOFUN), the Cottage and Small Industry Development Board (CSIDB), the Asia Network for Sustainable Agriculture and Bioresources (ANSAB), the Bhaktapur Craft Paper (BCP), the Livelihoods and Forestry Program (LFP), the Nepal Herbs Management Center (HMC) and the Bhimapokhara Youth Club (BYC).

During the first field visit in February-March, 2008, the baseline information was collected from 31 community forest user groups (CFUGs) of the selected VDCs. A group from each CFUG was formed for discussion, and it comprised of the executive committee members, women, lower castes, youths and seniors. During the second field visit (April-June, 2008), information on NTFPs VC was collected through a series of group discussions. Checklists were used to track discussions on the given issues.

Key informant interviews were conducted with NTFPs collectors/harvesters, middle-men, processors and traders, by using open-ended questionnaires. Informal meetings were held with individuals from the District Forest Office (DFO) and concerned Range Post (RP), CSIDB, DDC, FECOFUN, LFP, BCP, ANSAB, BYC, HMC, Agriculture Development Bank, local financial institutions and Community Based Organizations (CBOs). The availability of NTFPs resource was observed in most of the community forests (CFs). Secondary data were obtained from operational plans (OPs) and constitutions, minutes, and other records of CFUGs, DFO and other organizations. The data collected through different methods and from different sources were cross-checked through triangulation to improve the reliability of the results. Both qualitative and quantitative tools were used for data analysis.

Results and discussion

NTFPs Selection

Several meetings and discussions with CFUG members and other stakeholders were conducted and secondary data were reviewed to identify the potential NTFPs of the study area. A total of 22 NTFPs (excluding duplication) were identified and then narrowed down to 5, through the Attractiveness Matrix and Ranking Matrix analyses.

The Attractiveness Matrix Analysis was carried out with each CFUG separately, by reckoning the number of beneficiaries and potential for increase in income and later compiled into a single matrix. The matrix revealed that Lokta *(Daphne* spp.*)* and Allo *(Girardinia diversifolia)* were the most attractive NTFPs. Following them were Jhyau *(Lichen* spp.*),* Khoto *(Pine resin),* and Nigalo *(Arundinaria falcata)*. These five NTFPs were ranked along a weighing scale of 1 to 5 (where 1 was for the least important criterion) and a rating value for each product to derive a cumulative score. The cumulative scores from each study site were averaged to derive a total weighted score for the district (Table 1). The results suggested that the total weighted scores for Lokta was highest at 73 while Khoto received the lowest score of 37. In this paper, only the first two NTFPs, Lokta and Allo, have been selected for the VC analysis of the major NTFPs.

Lokta

Lokta is a wild shrub which grows gregariously and abundantly in most Himalayan forests of Nepal between altitudes of 2,000 to 4,000 m (Subedi *et al.*,

Table 1: Results from Ranking Matrix

Criteria	Weight	Proposed VC				
		Allo	Lokta	Jhyau	Nigalo	Khoto
Growth Potential (market, production, competition)	5	4 (20)	4 (20)	3 (15)	2 (10)	2 (10)
Scope (producer, area, income, consumption)	3	4 (12)	5 (15)	4 (12)	3 (9)	3 (9)
Poverty reduction potential, social benefits	4	3 (12)	5(20)	3 (12)	3 (12)	2 (8)
Prospects for **success,** conducive policy and social environment	2	4 (8)	5 (10)	3 (6)	3 (6)	3 (6)
Traditional knowledge and skill	2	4 (8)	4 (8)	2 (4)	4 (8)	2 (4)
Total Weighted Score		**60**	**73**	**49**	**45**	**37**

Note: Rating '1' is the lowest and '5' the highest

2006). It is a self-regenerating plant; once harvested, it takes about 6 to 8 years to be fully matured and ready for extraction. An estimated figure of 110, 481 MT (metric ton) of raw Lokta is available in Nepal; however, only about 800 to 1,000 MT are collected each year (HANDPASS, 2003, quoted in Banjara, 2007). In Baglung district too, there is less collection of Lokta than what was available. As reported by BCP, only about 5 MT is harvested each year from Baglung and the two adjoining districts (Parbat and Myagdi) although there was a potential to harvest 90 MT.

Lokta paper, manufactured from the inner bark of the plant, is made in remote hilly areas by the local farmers at a household level or by entrepreneurs on a large scale. In recent years, many CFUGs have also started to produce the paper on larger scales by establishing community-based enterprises (Gauli and Baral, 2008). The price of paper was found to vary in different locations depending mainly on the extent and type of transportation facilities to the market; quality and quantity of paper that can be supplied; and the dealings with contractors and local producers. Lokta prices were higher in the capital because of the additional cost levied on them in terms of taxes and transportation (Olsen and Helles, 1997). During the field study, the average price per kori (200 sheets) paper, based on quality of the paper, ranged between NRs. 1400 and 1800 (US$1 is about NRs. 70) in Kathmandu while the same ranged between NRs. 900 and 1500 in Baglung.

Historically, Lokta paper has been used for most of the government documents and religious texts in Nepal. Nowadays, it is used mainly for producing stationery products, wrapping papers, boxes and bags, greeting cards, *Thankas* (Tibetan paintings) and wallpapers. According to Banjara (2007), 90 % of the paper products made in Katmandu were exported mostly to Europe and America while the remaining 10 % were consumed locally.

Allo

Allo is a fiber yielding wild herb also known as Himalayan Nettle. It grows in high mountain regions of Nepal at an altitude of 1,200 m to 3,000 m flourishing under the shades of mixed deciduous forests (www.everesthandicraft.com). When harvested correctly, Allo regenerates abundantly the following year. Out of the many NTFPs, it has been identified as one of the resources with potential for rural enterprise development and a base for sustainable livelihoods of the rural areas (MEDEP, 2001).

Like the Lokta paper, the price of Allo products also varied with the market parameters and locality. During our study, the price of thread ranged between NRs.

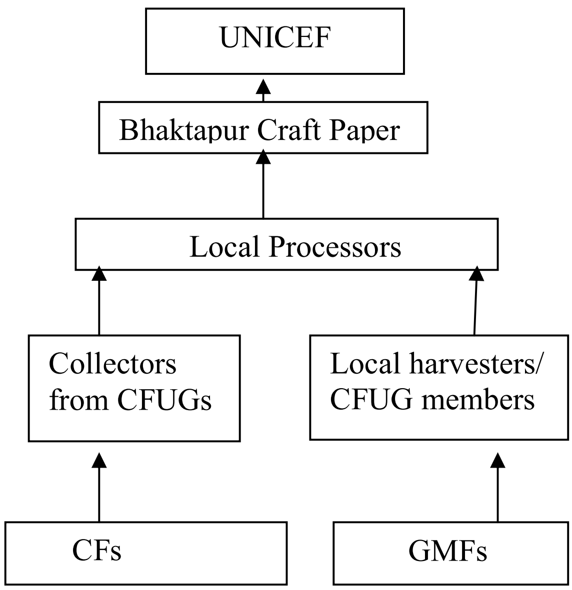

Fig. 1 : Value chain map of Lokta

300 and 400 per kg in Baglung; and between NRs. 450 and 600 in Parbat. This plant has provided raw material for making most of the textiles needed by households for generations. Local people mainly spun the Allo fiber to weave jackets, porter's headbands, fishing nets, ropes, snacks bags, mats, etc. Other uses of this plant were as vegetable of young shoots by poor people and for animal fodder with leaves and shoots.

Value chain map

A two-phased process for developing the VC map was carried out: (a) initial basic mapping after the desk review and the first visit; and (b) adjusted mapping including revisions based on group discussions, key informants interview and feedback from groups and individuals brought into the analysis process. The VC maps of Lokta and Allo are depicted in Figure 1 and Figure 2.

Four main types of actor were involved in VC of these products: 1) collectors/harvesters 2) local processors 3) local traders/urban wholesalers and 4) national traders/urban exporters. Each actor added value to the product along the VC from the transformation of raw material ultimately into marketable finished products. However, the share of benefits that collectors received was significantly lower than those received by other actors (Biggs and Messerschmidt, 2003). In the study site, Lokta collectors sold dried bark to local paper producers, while few of them sold to traders who transported directly to the capital. In Taman VDC, there were about 60 household-level paper producing units where entire family members were involved in paper making or collecting barks from their own forests. BCP, Baglung purchased all the paper sheets from them and delivered to their head office in the Kathmandu valley, where various products and supplies, most of them to United Nations Children's Fund (UNICEF), were manufactured. UNICEF's Greeting Cards Operation is BCP's primary wholesale market, accounting for approximately 90 % of sales, under an exclusive contract.

As per Allo, only CFUGs members harvested it from their own forests. Sometimes, they along with the local people collected it from government managed forests (GMFs) and farm lands. Most of the collectors sold dried bark to either processors or traders, but a few made thread themselves. Thread was the final product of Allo in the study site as there

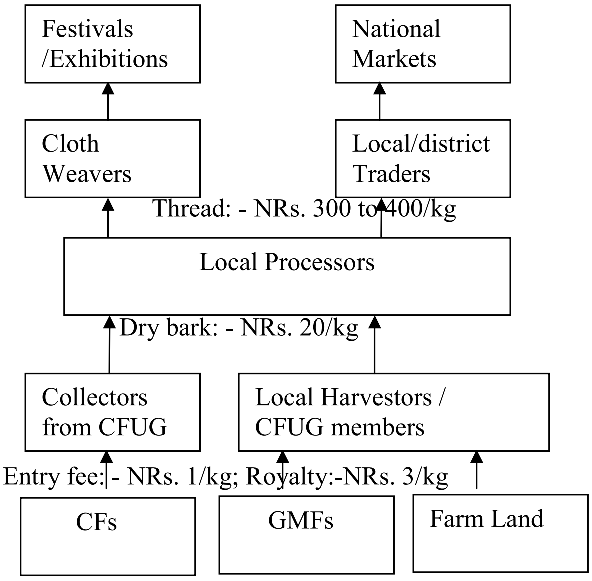

Fig. 2: Value chain map of Allo

was no cloth weaving enterprise till now. Local processors sold thread to either local traders or to cloth weavers in the nearby villages. The traders sold the thread to cloth weaving companies in the capital. The cloth weavers of the neighbouring village have been selling their products mainly during festivals and local exhibition programs and, therefore, do not have fixed markets.

Communities received almost all the required NTFPs-business development services directly from facilitating organization in remote parts of Nepal (Gyawali and Panta, 2007). In Baglung too, there were many SPs involved in Lokta and Allo VCs. The Department of Forest (DoF) and its sub-ordinates (DFO, RP) provided technical and legal support throughout the whole chain. Similarly, the concerned CFUGs were also active in raw material production and legitimate collection. Other organizations such as BYC, HMC, CSIDB, LFP, and FECOFUN were also providing support services to local people in processing. In addition, BCP, since its establishment in 1990, has assisted paper processors with input supply such as caustic soda. ANSAB started its work in Baglung for Lokta VC promotion from 2001. It has been active for the VC promotion during this study period mainly in NTFPs inventory, enterprise plan development and marketing.

Opportunities and constraints

VCA can be used by grassroot organizations to increase knowledge of opportunities and constraints throughout the chain and it can also contribute to strategic learning for enterprise development (Mayou, 2003). In this study, major constraints for running Lokta and Allo-based enterprises were identified and possible opportunities were explored. Business solutions have been recommended and are discussed under the following sub-headings of the major components of an enterprise.

Technology and product development

Rural people have been making Lokta paper with traditional technology and have borne the relatively high cost of production. Moreover, most of them were compelled to sell the paper at low prices mainly because of the low quality resulting from a lack of knowledge about quality parameters. Subedi *et al.*, (2006) had recommended training for paper producers on paper production and quality management. The promotion of quality paper-making has the potential to enhance their economic status (Banjara, 2007). The authors had recommended refresher training about BCP paper quality to increase paper price, and the demonstration and promotion of modern technology such as the beater machine to reduce the cost of production. The presence of some trained persons, who could run beater machine manually in the nearby villages, is an opportunity.

The Allo processing system adopted in the study site was also a traditional one, consisting of self-made, hand-operated machines (*Firfire*, *Hate Charkha)* which, according to key informants, were time consuming and increased the cost of unit production. The reasons for using them were their lack of knowledge about modern processing equipments, such as leg-operated machine (*Khutte Charkha)* and spindle with a wheel for spinning fiber and also in understanding quality parameters. These constraints had prohibited them from reaping optimum monetary benefits. Therefore, cost and benefit analysis of traditional and modern methods are recommended and then this information about efficient processing technology and quality parameters should be disseminated. In the study site, none of the processors had made clothes and other textile products as they were not well trained and so they hesitated to prepare them. SPs were suggested to transfer knowledge and skills for product development by organizing trainings, workshops and exposure visits that provide rural people opportunities to learn about modern technology, exchange information, and develop commercial linkages with other actors of VC.

Market access

The processors in the study site have been selling Lokta paper to BCP for many years. BCP has its own quality grading categories and associated prices. One of the pricing strategies was the use of paper size (i.e. 19.5" * 26"), which was different from the usual size found in the capital. This has indirectly freed the processors to sell the paper exclusively to BCP. However, based on our quick survey, BCP price seemed reasonable considering other benefits provided to processors such as a subsidy on caustic soda and paper transportation costs. Therefore, an alternative market to BCP is not necessary at present; however, the entrepreneurs were encouraged to be aware of the pricing strategy of BCP and to demand for alternative markets. There was no good local market for Allo products and people were selling either Allo bark or thread to interested buyers at their own prices which were usually lower than the market prices.

Poor links to markets, inadequate market information and weak bargaining power were some of the constraints for forest-based SMEs (Elson, 2008). Furthermore, Pandit *et al.*, (2004) pointed out that the inadequate market information was one of the challenges for NTFPs-based enterprises in their study area. This situation was also hampering collectors to get appropriate price (Poudel, 2009). SPs were recommended to provide market information on buyer specification and standardization in regional and national markets and also provide access to new markets and outlets. According to Maraseni *et al.* (2006), helping collectors with credit, training and market information could be instrumental in teaching them to deal directly with wholesalers, with increased bargaining power and risk-bearing capacity. It is recommended that SPs facilitate the establishment of network among Allo thread makers, cloth weavers, and some entrepreneurs from neighbouring district have been found to be ready to buy threads at good prices.

Input supply

The abundance of resources with growing market demand suggests a great potential of NTFPs for enterprise development in Nepal (Subedi *et al.*, 2004). However, current practices or level of skills for NTFPs harvest and post-harvest operations were not satisfactory (Subedi, 1999). More than 90 % volumes of the commercial NTFPs were collected from the wild, very often in unsustainable manner (Poudel, 2009). In the study site, abundant Allo was growing naturally in the forest and surroundings, however, the collectors were harvesting without consideration for the season or the plant condition. Similarly, Lokta collectors also have been harvesting every type and quantity of raw material without considering the sustainability of the resources. This has resulted in low prices because of the poor quality and also the destruction of the resources.

Subedi *et al.*, (2006) had recommended training on sustainable Lokta harvesting and post-harvest handling for the collectors. The authors felt the immediate need for hands-on-training to collectors on sustainable harvesting and the formation of a network of collectors and processors for the regular supply of quality raw material without depleting the natural resources. Lokta processors used caustic soda provided by BCP. Allo processors would also like to use the same, but have been using ashes which they have better access to. However, they were recommended to continue using the same as it takes less time and foreign buyers preferred products cooked in ashes.

Financial access

The remote areas of Nepal have very few financial institutions, so financial service was a constraint for enterprise development in these areas (Gyawali and Panta, 2007). Although SPs had provided skill development trainings to poor users, often the users could not utilize that skill as a profession because they could neither launch any micro-enterprises on their own nor get any financial assistance from SPs (Paudel and Vogel, 2007). In this study site, local processors were poor and had difficulty in managing funds for buying processing equipment. The NGOs and CBOs had not provided financial support in enterprise development. In terms of opportunities, LFP (donor) has provision for financial support for this sector through either 'quick impact program' or 'machinery support'. Likewise, ADB and local cooperatives have provision to provide loan for forest enterprises. The NGOs and CBOs can disseminate information about these opportunities to communities and can help facilitate access to these loans and financial services.

Some CFUGs with good savings had not being able to mobilize their funds for enterprises such as shares and money lending to poor users at low (or free) rates of interest. This was primarily due to lack of knowledge in investments and, additionally, due to the reluctance of rich users to support poor users. It has been difficult task to convince people to mobilize local resources for the benefit of poor (Maharjan *et al.*, 2004); however, such situation can be greatly improved with facilitation through SPs, as mentioned in a case study in Bhodkhore CFUG, Parbat, by Paudel (2007). Bhodkhore CFUG had started a 'Revolving Fund for poor' program to invest in income generating activities like bamboo-basketry, goat-farming, and the like. We also recommend the establishment of 'enterprise development revolving fund' within enterprise groups or within CFUGs, and to provide orientation to CFUGs about business accounting and fund mobilization. This way, entrepreneurs can have easy access to financial services from all possible sources.

Regulatory policy

The Forestry Sector Policy (2000) had emphasized the promotion and commercialization of NTFPs, including their export to foreign countries after value-addition. The policy also encourages local communities to establish forest-based processing enterprises. The government has fixed royalty rates for NTFPs through the Forest Regulation 1995, and these have been revised twice in line with market price of the products. The CFUGs of study site usually sold the products at the government royalty rates. Many CFUGs were not aware of their selling rights, irrespective of the government royalty as mentioned in the Forest Bill of 1990 (Shrestha, 1998). The government had also developed the Herbs and NTFPs Development Policy (2004) with the long-term goal to substantially contribute to Nepalese economy by conserving and preserving high value herbs and NTFPs. Though the policy mentions simplification of tax system for privately grown NTFPs, it das been silent on CFs. There is also a contradiction in controlling taxation system on forest products between Forest Act (1993) and Local Self Governance Act (1999). Multiple taxation also exists due to taxes collected both by central and local governments on NTFPs trade.

Most of the community people in rural parts of Nepal including the site were unaware of the government policy about the use of natural resources. Therefore, it is recommended that awareness raising programs on natural resources policy at local level be conducted. It also seems necessary to provide trainings on right-based approach. With regard to marketing, BCP has been helping in legal process because of an agreement with the government for marketing of Lokta from national forest which also includes CF. For Allo, DFO Baglung seemed to be positive for its marketing.

Organizational management

Until this study was conducted, none of the OPs of CFs had any detailed inventory or management plan for NTFPs and most of them had already expired. Not only was the case in this study site but similar results were also observed in several studies (e.g. Pandit and Thapa, 2004; Kanel and Kandel, 2004). Most of the CFUGs were not able to collect revenue from the NTFPs trade, as their OPs did not sufficiently account for their management and marketing. Therefore, they were suggested to include detailed management plan for NTFPs in OPs and become aware about the legal ownership of their forest resources. As an opportunity, LFP had provisions for financial support for OP revision through DFO/ NGOs. Likewise, ANSAB has also committed to get involved in this process mainly in NTFPs inventory. CFUGs were recommended to exploit these opportunities with the facilitation of SPs.

The collectors/processors in the study site seemed to work individually and were not organized. This has affected their bargaining power and benefits. According to Poudel (2009), profit margins of collectors were less than 10 % of the final price. A formation of sub-group of NTFPs collectors/ processors within CFUGs was recommended to establish their village level network. Social mobilization was also necessary to make the group stronger in organizational development. Support for making an appropriate enterprise model with detail enterprise development plans for each individual enterprise has also been recommended.

Infrastructure development

Since many high-value NTFPs were located in very remote areas, processing and marketing costs were generally high (Subedi, 1999). Poor infrastructure for product transportation has been one of the major hindrances to the marketing of NTFPs (Poudel, 2009). This also holds true for the study site. However, the construction of earthen roads to the nearby villages was on-going, and this will help for easier transportation. Poor communication and electricity supplies were the other problems hindering the adoption of advanced technologies on enterprise development. The local government was active in supporting infrastructure development. SPs were recommended to lobby for this process.

Conclusion

Lokta and Allo were the two major NTFPs of the study site. The detailed study of their VCs demonstrated that there was an urgent need for skill development trainings, mainly in sustainable harvesting, processing and products development, and exploring detailed information about the possible markets. The entrepreneurs could be more efficient, increase their productivity and reduce the unit cost of production by using appropriate technology. As local processors were poor, they need basic support services either from CFUGs' fund or from financial institutions. Potential SPs of the study site are suggested to consider the loopholes of VCs, and put an effort to make the NTFPs-based business more competitive and profitable for the sustainable rural livelihoods development.

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Short note

Dendrochronology and climate change study in Nepal: a preview

P. K. Chhetri[1], K. B. Shrestha[2]

The needs for advanced studies on impacts of climate change have been realized. In this study, the major focus is on changing climatic pattern and increasing natural hazards and its environmental consequences in Nepal. The climatic records of Nepal extend back to a relatively short period and may not adequately represent the range of natural climatic variability. A long term climatic data is needed to understand ongoing climate change phenomenon. In the recent decades dendrochronological data have been widely used in the world as a long term, high resolution, proxy of climate change.

Dendrochronology is a branch of science which deals with the study of tree rings. Dendroclimatology reveals the relationship between past climate events and annual tree growth. The annual rings of trees can be important sources of long-term paleoclimatic data if they are dated accurately. However, the properties of tree rings can vary in response to climate change. Using trees growing in a particular sites where climate has been highly limiting to the process of tree growth, the features of dated rings can be averaged year by year to obtain a time series of the growth response to past variations in climate (Frits, 1976).

Cook *et al* (2003) and Sano *et al* (2005) have demonstrated the possibility of reconstructing past climate in Nepal Himalaya by using dendroclimatic techniques. Therefore, dendrochronological study can not only come up with paleoclimatic information, but also help in understanding climate change phenomenon.

Current status of dendrochronological study in Nepal

Dendrochronological work in Nepal was started by Rudolf Zuber under the supervision of Fritz Schweingruber. This work was followed by many other research scholars (Suzuki, 1990; Bhattacharya *et al.*, 1992; Cook *et al.*, 2003; Sano *et al.*, 2005). *Abies spectabilis* has been the most studied species but there have been many other potential species, such as *Pinus roxburghii, Pinus wallichiana, Tsuga dumosa, Picea smithiana, Juniperus recurva, Ulmus wallichiana, Cedrus deodara, Larix potanini* .

Tree ring in climate change study in Nepal

In Nepal, dendrochronological study began in late 70s but it was used in climate change study only after 2003. Suzuki (1990) and Bhattacharya *et al* (1992) hinted about the potentiality of different species for dendroclimatological studies. Cook *et al* (2003) reconstructed February-June and October-February temperature, back to 1546 AD and 1605, respectively. This was considered as the first reconstructed temperature of Nepal. Each reconstruction confirmed the occurrence of unusually cold temperatures in 1815-1822, which coincided with the eruption of Tambora in Indonesia. The October-February climate reconstruction demonstrated evidence of late 20th century global warming trend whereas the February-June temperatures indicated cooling trend since 1960.

Sano *et al* (2005) reconstructed the past 249 years climate of western Nepal using ring width and wood density of *A. spectabilis*. This reconstructed temperature for the past 249 years showed a warming trend from 1750s until approximately 1790, followed by cooling until 1810, then by a gradual warming trend well up to 1950. A notable cold period continued up to the present which did not support the consensus of recent global warming.

Since various studies considered dendrochronology as an appropriate and effective tool for prediction of past climatic information, only the systematic dendrochronological study can deal with the climate change phenomenon. The potential areas for future

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dendrochronological studies in Nepal are discussed below.

Future focus

Western Nepal climate is influenced by both Eastern and Western Monsoon. So, there is a higher probability of finding potential climatic signals in western Nepal than in eastern Nepal. The southern margin of vegetation distribution (Tropical to temperate margin) has *P. roxburghii* and *P. wallichiana* as highly potential tree species.

More studies should be focused on tree line area to investigate the effect of recent global warming on tree line phenomena. The fluctuation of tree line position, growth dynamics pattern due to the climatic variability and the effect of human land-use can be of interest. For such studies tree line forming species like *A. spectabilis, T. dumosa* can be used as potential species. The responses of tree line species to the global warming over the last century have been detected in many parts of the Northern Hemisphere (e.g. Rochefort *et al.* 1994; Peterson *et al.*, 2002) by evaluating tree seedlings, invading above the current tree line.

Only two studies (Schmidt, 1993, Schmidt *et al.*, 1999) were found on archeological sites. Many centuries old Gumbas and Temples. are widely distributed in Nepal. Dendrochronological studies focusing on wood samples from these monuments will help to reveal past environment. The protential for of isotopic tree ring study is also high in Nepal. Many isotopic tree ring studies have already been carried out in India.

Strong dendrochronological network is needed to be developed to understand the current phenomenon of climate change. It should cover a variety of species and ecological conditions. Topography, relief, micro-catchments should be considered while collecting samples. Thus, constructed past climate will help us understand the climatic variability in Nepal as well as the whole South Asian region.

Conclusion

Nepal has a wide distribution of dendroclimatologically potential species; but in comparison to neighbouring countries and other mountainous regions, the related studies have been very limited in Nepal although climate change is more pronounced in Nepal Himalayas and can have severe impacts on livelihoods. Systematic climatic studies based on tree rings can help us understand the ongoing climate change pattern.

So it is recommended that more micro-climate related dendrochronological researches are carried out. Dendrochronology ought to be included in the university curriculum in Nepal.

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