UNIVERSITY OF SOUTHERN QUEENSLAND

AN EVALUATION OF REDD+ IN COMMUNITY MANAGED FORESTS: A CASE STUDY FROM NEPAL

A Dissertation Submitted by

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CERTIFICATION OF DISSERTATION

I certify that the ideas, research works, results, discussions and conclusions reported in this dissertation are entirely my own effort, except where otherwise acknowledged. I also certify that the work is original and has not been previously submitted to earn academic awards.

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LIST OF PUBLICATIONS AND AWARDS

List of journal papers during the PhD study

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3. **Pandey, S.S**, Cockfield, G., and Maraseni, T.N. 2013. Conservation of the forests with linking livelihood of local communities and REDD+ in Nepal. In: Burns, R.C. and Highsmith, J. (Eds.) *Book of Abstracts*. IUFRO Conference on Forests for People. Traverse City, Michigan (May 19–23, 2013) p.56 http://www.recpro.org/assets/Conference_Proceedings/ffp_abstract_book_final.pdf

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ABSTRACT

Deforestation and forest degradation contribute between 10 and 25% of total annual greenhouse gas emissions. The REDD+ program for reducing emissions from deforestation and forest degradation and promoting forest conservation, sustainable management of the forests and enhancement of forest carbon stocks is one mechanism developed in an attempt to mitigate greenhouse gas emissions. Various REDD+ initiatives have been trialled in developing countries, including for community forests (CFs), which are an increasingly common form of resource management. Through the program, incentives are provided to community forest user groups (CFUGs) to encourage changes in management practices likely to increase sequestration stocks. There is, however, limited knowledge about the factors responsible for enhancing carbon stocks in CFs, the likely trade-offs within communities and the potential for increasing sequestration stocks.

The overarching goal of this research is to evaluate the impacts and potential of REDD+ projects in CF systems. Results from this study provide information for the design and development of programs to increase sequestration and conservation benefits in developing countries. This study estimated carbon stocks and change in carbon stock, technical potential (maximum stocks), key factors affecting carbon stock and trade-offs between gains in sequestration and other foregone community benefits. The study covered 105 CFUGs operating within five major dominant vegetation types. Annual data of carbon pools comprising above and below ground biomass were used to analyse carbon stocks and stock changes. Where sufficient data and models for key species were available, the potential carbon stock was estimated. Social, economic and management data, including a review of existing relevant documents, key informant survey and focus group discussion were used to identify major drivers of forest carbon stock changes in CFs and added community effort and foregone cost added for REDD+. Total costs of REDD+ participation were compared with the potential carbon benefits to enable trade-offs to be identified.

This study found variations in sequestration rates between CFUGs. Key variables were species type, canopy cover, elevation, age, forest scale, agriculture landholding size, disturbance levels, biomass extraction and the use of alternative energy sources.

In comparing present carbon stock with the technical potential of carbon stock in forests, the study identified significant potential for REDD+ projects to increase carbon stock in CFs.

On the negative side, changes in management practices added costs to communities, either through loss of forest products or through additional REDD+ activities, to the extent that the pilot REDD + projects were generally not economically beneficial for CFUGs. However, they could be made more beneficial with a reduction in the opportunity cost of community engagement (through scheduling) and the bundling of other non-carbon benefits together with carbon benefits. Outcomes could be improved through reducing ‘leakages’ resulting from a high dependency on forest resources through strategies such as the promotion of alternative energy sources (e.g. improved cooking stove and biogas).

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ABBREVIATIONS

3PG	Physiological Principle Predicting Growth Model
AGTB	Above Ground Tree Biomass
AGSB	Above Ground Sapling Biomass
AFOLU	Agriculture, Forestry and Other Land Use
ANSAB	Asia Network for Sustainable Agriculture and Bioresources
BEF	Biomass Expansion Factor
BGTB	Below Ground Tree Biomass
BGSB	Below Ground Sapling Biomass
DoF	Department of Forests
C	Carbon
CAI	Current Annual Increment
CBA	Cost Benefit Analysis
CBD	Convention on Biological Diversity
CDM	Clean Development Mechanism
CER	Certified Emissions Reduction
CF	Community Forest
CFUG	Community Forest User Group
cm	Centimetre
CO_2	Carbon Dioxide
CO_2e	Carbon Dioxide Equivalent
COP	Conferences of the Parties
DANIDA	Danish International Development Agency
DBH	Diameter at Breast Height
DHM	Department of Hydrology and Meteorology
EU-ETS	European Union Emissions Trading System
FAO	Food and Agriculture Organisation
FCPF	Forest Carbon Partnership Facility
FECOFUN	Federation of Community Forestry Users Nepal
FGD	Focus Group Discussion
FSC	Forest Stewardship Council
FullCAM	Full Carbon Accounting Model

g	Gram
GA	General Assembly
GHG	Greenhouse Gas
GIS	Geographic Information System
GoN	Government of Nepal
GPS	Global Positioning System
H	Height
ha	Hectare
HB	Herb Biomass
HH	Household
ICIMOD	International Centre for Integrated Mountain Development
ICS	Improved Cooking Stove
IPCC	Intergovernmental Panel on Climate Change
kg	Kilogram
LB	Litter Biomass
LPG	Liquefied Petroleum Gas
LSU	Livestock Standard Unit
LULUCF	Land Use, Land Use Change and Forestry
MAI	Mean Annual Increment
MFSC	Ministry of Forests and Soil Conservation
Mg	Mega gram
mm	millimeter
MMF	Morgen-Mercer- Flodin
MPFS	Master Plan for Forestry Sector Nepal
MRV	Measurement, Reporting and Verification
MSY	Maximum Sustained Yield
NARC	National Agriculture Research Coulcil
NARMSAP	Natural Resource Management Sector Assistance Programme
NORAD	Norwegian Agency for Development Cooperation
NSCFP	Nepal Swiss Community Forestry Project
NTFP	Non-Timber Forest Products
ppm	Part Per Million

REDD+	Reducing Emissions from Deforestation and Forest Degradation,Sustainable Management, Conservation and Enhancement of Forest Carbon Stock
PES	Payment for Ecosystem Services
R^2	Coefficient of Determination
REL	Reference Emission Level
SBSTA	Subsidiary Body for Scientific and Technological Advice
SD	Standard Deviation
SOC	Soil Organic Carbon
UN	United Nations
UNFCCC	United Nations Framework Convention on Climate Change
UNFF	United Nations Forum on Forests
UN-REDD	United Nations REDD+
US$	United States Dollar
VDC	Village Development Committee

CHAPTER ONE

INTRODUCTION

1.1. Background

Forest area loss is considered to be one of the major sources of greenhouse gas emissions (GHGs) (Fearnside 2000; UNFCCC 2014). Deforestation and forest degradation contribute 10–25 % of global anthropogenic emissions (Stern 2007; Van der Werf *et al.* 2009). To reduce deforestation and forest degradation, “REDD+” (reducing emissions from deforestation and forest degradation, conservation of the forests, sustainable management of the forests and enhancement of the carbon stock in the forests) has been trialled in developing countries (Olander *et al.* 2012; Streck 2012). REDD+ is expected to offer offsetting opportunities to Annex I countries (emitting more GHGs and with an obligation to reduce) for achieving their set targets of emission reduction while the non-annexed developing countries get income generating opportunities from their forest carbon enhancement performance (Angelsen 2009; Ghazoul *et al.* 2010).

The REDD+ program was instigated at the thirteenth session of the United Nations Framework Conventions in Climate Change (UNFCCC) Conference of Parties (COP 13) (Angelsen *et al.* 2012) and it is considered to be a primary agenda of the UNFCCC (UNFCCC 2007, 2010, 2011; Okereke & Dooley 2010; Szolgayová *et al.* 2014). Since 2007, many developing countries have initiated REDD+ readiness activities and demonstration projects (Cerbu *et al.* 2011). These initiatives are taking place under a number of bilateral and multilateral funding arrangements including the United Nations REDD+ (UN-REDD+) program and the World Bank’s Forest Carbon Partnership Facility (FCPF). These projects are implementing pilot activities for the REDD+ at both project and national levels (Angelsen *et al.* 2009; Blom *et al.* 2010; Hajek *et al.* 2011; Leggett & Lovell 2012).

While implementing REDD+ mechanisms, safeguarding social or environmental benefits and developing credible Monitoring, Reporting and Verification (MRV) guidelines have been identified as key issues which need to be addressed by researchers (Angelsen *et al.* 2012). These issues were raised during negotiations and the Subsidiary Body for Scientific and Technological Advice (SBSTA) requested that developing countries be provided with guidance and support to address them (Johns *et al.* 2008; UNFCCC 2011). As each developing country is unique in terms of its economic status (Lee 2005), each has different capacity to adopt new technologies (Comin & Hobijn 2004), each has specific forest management policies and practices (FAO 2011), and each may need context specific REDD+ mechanisms to address these issues.

Increased carbon stock in forests is a major outcome of the REDD+ mechanism and this needs to be estimated and accounted for as a product for carbon markets and the focus of forest owners and their project activities (Fry 2011; Angelsen *et al.* 2012). The rates of carbon stock change in forests may differ with different natural factors related to forests and socio-economic factors related to forest owners. This is important information when designing REDD+ policies and projects. There is a range of tenure arrangements from forests which are government managed, to those managed by individual people or companies, to forests managed by local communities or indigenous people (Siry *et al.* 2005; FAO 2011). The proportions of both government and individual/company-owned forests are higher in developed countries whereas community-owned forests are more common in developing countries (White & Martin 2002; Agrawal *et al.* 2008). Therefore, community forestry, a process whereby specific community forest users protect and manage state forests in some form of partnership with the government (Hobley 1996), is important for the REDD+ mechanism.

The area of community forests is increasing in Asia and Africa in order to conserve forest, fulfil subsistence needs for forest resources and improve livelihood opportunities of the forest dependent communities (Sunderlin *et al.* 2008). Nepal, a Himalayan country, provides a good example of community forests (CFs) with rights of forest management and sustainable use of more than 25% of national forests (1664 917 ha) afforded to 17,808 community forest user groups (CFUGs) representing more than 35% of the population (CFD/DoF 2013). The country has piloted Forest Stewardship Council (FSC) certification and has 21 CFUGs that have met the FSC forest management standards (Kanel 2006). A REDD+ community forestry (CF) pilot project was initiated by government and non-government organisations in 2009 (MFSC 2011). CFs can increase carbon stocks and contribute in sequestering atmospheric CO_2 (Maraseni *et al.* 2005) and the REDD+ interventions could be instrumental in improving both people's livelihood and carbon sequestration capacity of forests. However, REDD+ may require additional efforts and costs from communities, and poor forest dependent peoples would only be able to sacrifice the benefits they currently gain from forests if they get appropriate compensation from REDD+. Therefore there is nothing to be gained in implementing REDD+ in CFs if REDD+ carbon benefits are less than costs. Alternatively, CFUGs are able to improve the condition of forests after decade long management efforts and start to generate income by selling forest products (MFSC 2013) when benefits exceed costs. This is important for developing countries like Nepal where a total of 83% of people live in village areas, about 76% of households are involved in agriculture based economy (CBS 2011b) and farming practices are interrelated to forest resource extraction (Adhikari & Nagata 2004). Similarly, a total of 77% of total household energy demand is sourced from fuel wood in Nepal (WECS 2010) with forests the primary source.

In this context, there is a need to evaluate the REDD+ pilot projects to understand the carbon stock in CFs, factors affecting carbon stock and carbon changes, the maximum potential growth capacity of forests and the trade-off between carbon benefits and sacrificed benefits of the communities in REDD+ CFs. This knowledge may help to design REDD+ and similar programs. This PhD research strives to make a contribution on these issues by analysing an ongoing REDD+ pilot project in Nepal. In the next section, some of the issues related to this study are discussed.

1.2. Statement of the problem

The main policy problem driving this research is that forests are one of the key sectors in mitigating the rise in the level of GHGs (specifically, CO_2) in the atmosphere (Pachauri & Reisinger 2007; Stern 2007). Deforestation and forest degradation are main causes of CO_2 emissions with a global forest area loss of 5.2 million ha per year during 2000–2010 (FAO 2011). In order to reduce deforestation and forest degradation in developing countries, the REDD+ mechanism evolved after the Bali Action Plan (2007) and Copenhagen Accord (2009) as a potentially suitable market based mechanism (Grainger & Obersteiner 2011). There are possibilities to change the existing forest management practices of local communities to increase future carbon stocks through the REDD+ incentive based mechanism. CF is an important target form of management because forest dependent people have a history of collectively working and satisfying their subsistence forest product needs while improving forest quality (Yadav *et al.* 2003; MFSC 2013). In pursuit of the potential economic benefits of a future REDD+ mechanism, CFUGs could change their existing practices; however, this may add costs or increase sacrificed benefits and may change governance practices (Phelps *et al.* 2010). Therefore there is not appropriate to implement REDD+ in CFs if REDD+ carbon benefits will be less than sacrificed benefits. From a welfare economics perspective (Hochman & Rodgers 1969), these costs could and should be fully compensated in the REDD+ mechanism (Ghazoul *et al.* 2010).

CFUGs comprise different community groups in terms of castes and forest resource dependency, and also encompass a range of vegetation types (Springate-Baginski *et al.* 2003). According to the decision of the General Assembly (GA) of a CFUG and with the approval of the district forest office, communities can also change their existing use practices and forest management activities to further improve forests and generate greater REDD+ carbon benefits. These changed activities and practices may involve additional costs to these communities which need to be estimated and identified. Knowledge about the trade-off between a community's sacrificed benefits and the carbon benefits gained, and so also whether or not the REDD+ approach is appropriate for CFs, is limited. The following research gaps in relation to this problem were identified in the literature.

- *Knowledge gaps in forest carbon enhancement in CFs*

Most previous studies use governance as well as forest cover and the income of local users as indicators to evaluate the outcomes of CF management (Yadav *et al.* 2003; Acharya 2004; Gilmour *et al.* 2004; Sunderlin 2004; Sapkota & Odén 2008). However, there are few and limited studies about carbon enhancement with the incentive motivation of REDD+ in CFs. One limitation is that there is little attention given to the disaggregation of the carbon storage performance of forest species. CF systems in Nepal vary in terms of vegetation composition and species dominance (CFD/DoF 2013) so are likely to have different capacities for carbon growth with the adoption of REDD+ activities. Some studies related to carbon accounting in forests have been carried out in government managed and protected area systems (Singh *et al.* 1994; Wang *et al.* 2008; Sharma *et al.* 2010; Solberg *et al.* 2010; Usuga *et al.* 2010; Köthke *et al.* 2014). However, for designing an appropriate REDD+ project and benefit distribution of the carbon benefits within CF systems, the carbon enhancement status of different CFs needs to be estimated.

- *Knowledge about gaps between actual carbon stock in CFs and potential growth in undisturbed forests*

Quantification of the baseline or reference level of carbon stock is important to assess changes in GHG emission reduction projects (IPCC 2006). However, the literature on studies of tree carbon stocks in CF and in natural undisturbed forests, which would provide a benchmark for the full potential of these forests, is limited (Resosudarmo *et al.* 2012). If silvicultural activities are not appropriate, harvesting of forest products in higher quantities than the sustainable yield can reduce the biomass stock of forest stands (Foley *et al.* 2005; Hoover & Stout 2007; Chiang *et al.* 2008). Although, there is a specified provision of forest product harvesting and silviculture activities in operation plan of CFUGs; technical knowledge of communities and their implementation practices affect the outcomes (Pagdee *et al.* 2006). Therefore, the management practices of forest users in CF can lead to differences in carbon growth in managed forests compared to undisturbed forests. Estimation of carbon stock in both situations (i.e in CFs and without disturbances) is important to understanding the impact of CF. These difference will provide an idea about the maximum potential carbon benefits in CFs with REDD+ activities.

- *Knowledge gaps of major factors affecting carbon enhancement to design project activities to be targeted for REDD+ CF*

Forest based CO_2 emissions may be driven by various human induced factors including the conversion of forest land to agricultural land, illegal harvesting, infrastructure development, forest fires, encroachment and grazing (Geist & Lambin 2002; Pandey *et al.* 2013). Previous studies have found that the growth capacity of forests is strongly influenced by management practices (Hoen & Solberg 1994; Foley *et al.* 2005; Harmon *et al.* 2009). The sequestering of atmospheric CO_2 may depend on a forest's proximity to roads (Angelsen & Kaimowitz 1999) and settlements (Laurance *et al.* 2006), the rate of extraction of forest products (Harmon *et al.* 2009), livestock grazing (Blackmore & Vitousek 2000), agriculture landholding size (Adhikari *et al.* 2004), alternative energy sources (Katuwal & Bohara 2009), demographic factors (Jha & Bawa 2006), size of forests (Rudel *et al.* 2005) and age of forest stands (Pukkala *et al.* 2009). These may also differ in CFs where local communities are carrying out various forestry activities according to local knowledge and needs and the location of the forest area (MFSC 2013) but also in response to REDD+ economic possibilities. CFUGs may change existing practices in response to REDD+ incentives which may then change the status and carbon stock of the forests to an extent that is yet to be identified and analysed. Understanding of the major factors responsible for carbon enhancement in CFs is important in the design and implementation of REDD+ projects.

- *Knowledge gap about trade-off between community's sacrificed benefits and carbon benefits for REDD+ project in CFs*

An evaluation of the pilot project, particularly in terms of the trade-off between community foregone sacrificed benefits and carbon benefits, is important for the design and implementation of the REDD+ project. However, this has been found to be missing in the literature. Each community forest user group experiences real time benefits and costs in the management of a CF. Changes in existing costs (sacrificed benefits and added activities) and benefits (use of products, use of Non-Timber Forest Products (NTFPs) and ecosystem services including carbon) to communities due to the REDD+ (difference between before and after REDD+) is not well understood in the available literature. It is important that the community sacrificed benefits (cost) involved in enhancing carbon stock in CFs is evaluated holistically and that the REDD+ program is modified if necessary to ensure that communities are not disadvantaged through their participation.

1.3. Contentions to be tested in the study

This research was based on several contentions during data collection, analysis and interpretation:

- Stocking rates of trees is affected by silviculture operations (Nyland 1996) therefore forest biomass (and therefore carbon stocks and sequestration rates) in CFs is affected by management practices. These include harvesting and other disturbance practices. Due to these disturbances, actual potential carbon stocks in CFs may be much lower than technical potential carbon stocks in undisturbed natural forests.

- Carbon stocks and sequestration rates are affected by various biophysical and socio-economic factors which include altitude, age, forest canopy cover, species type, size of forests, caste heterogeneity, agriculture land holding size, forest product extraction and use of alternative energy sources (Rudel 1989; Smith *et al.* 1997; Cochrane & Schulze 1999; Pahari & Murai 1999; Geist and lambin 2002; D'Amato *et al.* 2011).

- REDD+ incentives may be insufficient (Ghazoul *et al.* 2010), especially in the long term, to offset the economic losses from changing management practices of communities.

1.4. Objectives of study

The overall aim of the study is to evaluate the feasibility of the REDD+ project in CF systems in Nepal by considering the gain in carbon stock in relation to costs incurred by communities. The objectives (with research sub-questions) are to:

a) Estimate carbon stocks and annual carbon stock changes in REDD+ CFs by vegetation type:
  - What is the total carbon stock in CFs by dominant vegetation types for a reference year of the REDD+ project?
  - What are the dynamics of carbon stocks in REDD+ CFs by different vegetation types?

b) Estimate the technical potential carbon stock of undisturbed forests and actual carbon stock in CFs by dominant vegetation types:
  - What is the technical potential of carbon growth in CFs by dominant vegetation types?
  - What is the actual carbon growth in CFs by dominant vegetation types?
  - What is the gap between actual and potential carbon stocks in CFs by dominant vegetation types?

c) Identify and analyse key factors affecting carbon stock changes in CFs:
   - What is the occurrence of biomass reduction activities after REDD+ in CFs?
   - What are the key biophysical and socio-economic factors affecting carbon stock changes in REDD+ CFs?

d) Identify and estimate trade-offs between carbon benefits and net sacrificed community benefits for REDD+ in CF:
   - What community benefits are sacrificed to enhance carbon stocks in the REDD+ CFs?
   - How much community benefit is sacrificed to enhance per unit amount of carbon stock in the REDD+ CFs ?

1.5. Justification of the study

This study investigates the impact of REDD+ in CF because, while the UNFCCC has agreed to use REDD+ as a climate change mitigation option to be implemented in developing countries with an incentive mechanism (UNFCCC 2007), it is not clear that it will be an effective implementation mechanism; CF in some developing countries is recognised as a successful forest management system which respects traditional practices, fulfils local needs and generates incomes for the local people (Gilmour *et al.* 2004; Nurse & Malla 2006). Nepal is one of the leading countries which have been successfully implementing CF from last three decades (MFSC 2013).

This study selected to study CFs in Nepal because the Nepalese CF provides a successful model for adoption in other developing countries (Brown *et al.* 2002); the present CF system in Nepal has been developed from long experience (CFD/DoF 2013; MFSC 2013); government and nongovernment organisations in Nepal have been involved in REDD+ pilot initiatives in CF; and the Government of Nepal has established a separate institutional structure (REDD- Forestry and Climate Change Cell) under the Ministry of Forests and Soil Conservation (MFSC) to facilitate REDD+ activities. Moreover, a multi-partner REDD+ project in CF was implemented in Nepal from 2009 which provided ground for researching community efforts and carbon stock relationship (MFSC 2011). Finally the author has had a personal involvement in CF and earlier worked on the REDD+ pilot initiatives in Nepal. Although this study was conducted in Nepal, the overall framework of the research could be replicated and the knowledge generated from the study may be applicable in other developing countries.

1.6. Scope and significance of the study

On average, the global surface temperature has increased by 0.2°C per decade over the past 30 years (Pachauri & Reisinger 2007). Changes in the global temperature are resulting in changes to ecological systems and a shift in the habitats of many plants and wildlife (Walther *et al.* 2002) and an increase in extreme climatic events (Beniston & Stephenson 2004). Therefore, global negotiations are around the agenda of halting global temperature increases below 2°C above the pre-industrial period to reduce climate change risks, impacts and damages (Pachauri & Reisinger 2007;

Meinshausen *et al.* 2009). Among different climate change mitigation options, the UNFCCC has agreed upon a REDD+ incentive based mechanism to be implemented in developing countries but scientific inputs are lacking (Caplow *et al.* 2011). This is important in CFs because the participation of local communities and the safeguarding of socio-economic benefits are issues for REDD+ (UNFCCC 2011) and the proper management of forest resources is suggested for poverty reduction and environmental sustainability by United Nations Forum on Forest (UNFF 2011). Without knowledge of the trade-offs between community's added foregone costs and carbon benefits, REDD+ may lead to perverse incentives and may not address, but exacerbate, existing social, environmental and climate change problems. Therefore, this study is crucial to policy decisions.

Reducing poverty of the forest users through the sustainable use of forest resources is one of the key aims of CF (Mahanty *et al.* 2009). Existing CFs provide subsistence products to the communities that conserve forests but may not be enough to bring these communities out of poverty especially in rural area where limited economic options are provided (Edwards 1996; Subedi 2006). Previous studies suggest implementing economically oriented CF to address poverty issues in developing countries (Edwards 1996; Gilmour *et al.* 2004; Subedi 2006). This study provides learning and new knowledge for consideration during the design and implementation of REDD+ and other incentive based conservation projects in CF.

As a least developed country, the government of Nepal is also moving towards REDD+ initiatives under multinational (UN REDD, World Bank forest carbon partnership facility -FCPF) and bilateral (US government, Norwegian government) funding schemes. The Government of Nepal has agreed to facilitate a nested approach (both national and subnational level) to REDD+ projects (MFSC 2011). However, the effective implementation of the REDD+ project needs a fair benefit distribution mechanism (Hoang *et al.* 2013) which accounts for foregone costs. The finding of this study can help to make appropriate policies that consider both community costs and carbon benefits in CF.

1.7. Structure of the thesis

This thesis is divided into nine chapters. In the first three chapters, the introduction, review of relevant literatures and research methodology used for this study are included. The introduction chapter provides the background, research problem, objectives and significance of the study. Chapter Two reviews the existing literature on carbon sequestrations dynamics and the economics of REDD+ in CFs. In this chapter, knowledge gaps, theoretical perspectives and issues related to REDD+ and CFs are identified. In Chapter Three, the detailed methodologies used to address gaps identified in the literature review and specified in Chapter One are presented. The fourth, fifth, sixth and seventh chapters give the results of the study. Chapter Four gives the dynamics of the stocking rates of different sized trees, carbon stocks in CFs for the reference year (2010) and changes after REDD+ project activities in CFs. Chapter Five gives actual carbon stock and potential maximum carbon stock growth in CFs. Chapter Six investigates changes in the behaviour of communities with REDD+ and key factors affecting carbon stock differences in CFs and Chapter Seven looks at the trade-offs between sacrificed benefits of communities for carbon benefits under the REDD+ mechanism. Finally, Chapter Eight and Nine discuss and summarise the major findings of the study, its research contribution and implications and makes suggestions for future research.

1.8. Conclusions

The REDD+ mechanism for developing countries is a promising concept which provides offset options to developed countries and income generation opportunities to poor forest dependent communities. CF is a participatory forestry practice that may demand additional efforts and changes in the existing practices of communities. For its long term success, an effective design and implementation of REDD+ in CFs is required; this could be better if it is based on knowledge about existing carbon stocks, the carbon stock increment potential, factors affecting carbon stock differences in CFs and trade-offs between community foregone sacrificed benefits and carbon benefits.

This chapter identified problems and gaps in the literature. Since REDD+ is new mechanism, knowledge generated from field based studies is limited. The broad aims and specific objectives of the study supported with research questions and contentions are listed. Justification and scope, as well as the significance of the study are also highlighted. Outcomes of this study may be useful to assess possible carbon benefits in other CFUGs while designing and implementing the REDD+ projects in future. Now many institutions are working on the REDD+ mechanism in Nepal and can be benefited from this study to design and implement better REDD+ projects. Issues related to carbon sequestration dynamics in forests, factors affecting carbon stocks, economics of REDD+ in CF, methodologies related to carbon pool measurements are reviewed in existing literatures and presented in Chapter 2.

CHAPTER TWO

A REVIEW OF THE CARBON SEQUESTRATION DYNAMICS AND ECONOMICS OF REDD+ IN COMMUNITY FORESTRY

2.1. Introduction

Chapter one explains about major knowledge gaps on possible outcomes of the REDD+ projects in CFs, research questions for this study and its significance. This chapter includes a review of some relevant issues about climate change, the role of forests in mitigating climate change and mechanisms for reducing GHG emissions from forestry sectors. This chapter includes ten sections. The next section reviews the literature related to climate change and the role of forests in mitigation measures. The third section gives information about carbon pools and carbon pool measurement practices in forests, the fourth section includes reviews regarding possible factors affecting carbon stock changes in CFs, the fifth section covers the economics of REDD+ in CFs while the sixth section includes a review of research methods in CF. In the seventh section, the chapter covers existing knowledge about carbon prices in global markets and, in the eighth section, reviews existing yield models for forest growth prediction. The ninth section highlights information about theoretical aspects related to REDD+ in CFs and the final section provides a conclusion to the chapter.

2.2. Climate change and role of forests in mitigation measures

2.2.1. Climate change and share of forestry sector in global GHGs emissions

Average global temperatures increased in the late 20th century. The rate of global surface temperature increase has been about 0.2°C per decade over the past 30 years (Hansen *et al.* 2006; Pachauri & Reisinger 2007). Global temperature increase and climate change are used interchangeably in literatures (Stern 2007; Shi *et al.* 2010; Cook *et al.* 2013). Anthropogenic activities are considered the main causes of climate change (Tett *et al.* 2002; Cook *et al.* 2013). According to the fifth assessment report of the Intergovernmental Panel on Climate Change (IPCC), GHG emissions from 2000 to 2010 have grown at about twice the rate observed in the decade from 1970. Of all anthropogenic GHGs, CO_2 was responsible for about 55% of total emissions in the decade from 1970 and 65% of emissions in the decade to 2010 (Victor *et al.* 2014). Out of five major sectors examined, Agriculture, Forestry and Other Land Use (AFOLU) contributed 24%. Within total emissions of each economic region, the AFOLU related emission is higher in lower income regions than higher income (Figure 2.1). Therefore, addressing emissions related to AFOLU in developing countries is important.

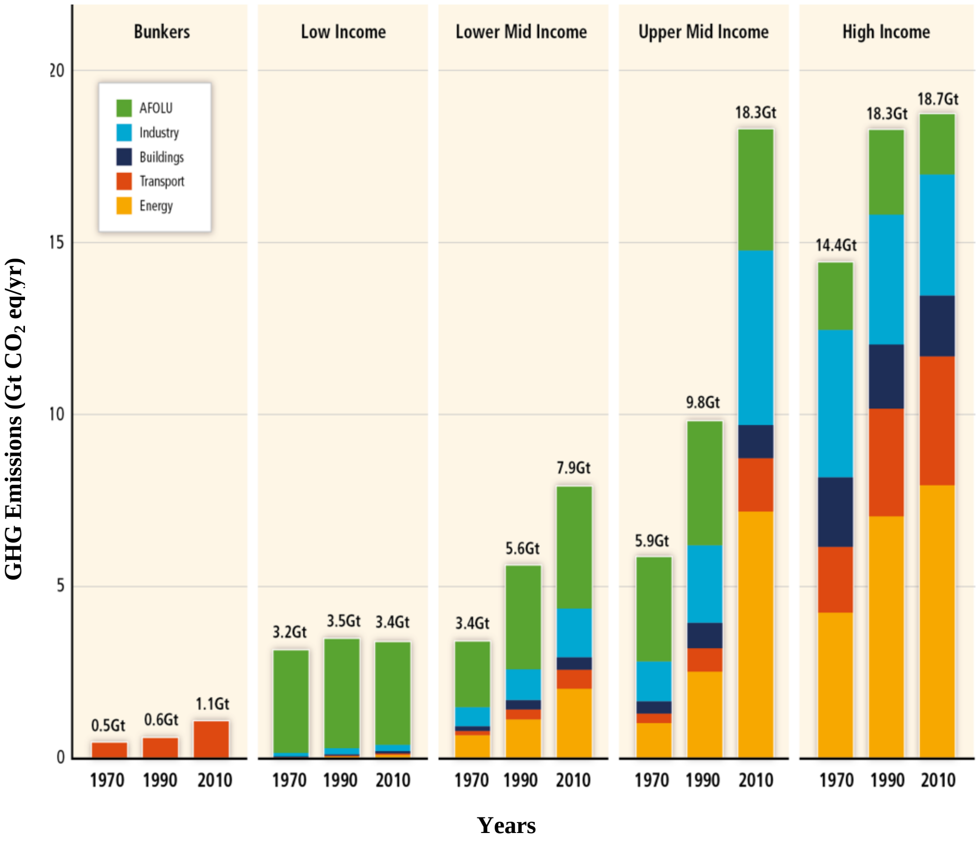


Figure 2.1 Greenhouse gas emissions (CO_2-equivalent) measured in 1970, 1990 and 2010 by five sectors in four economic regions (Source: Victor *et al.* 2014)

Within AFOLU, deforestation and forest degradation contribute significant emissions. The forestry sector is important, storing huge quantities of carbon stock. At present, forests occupy 30% of the global land area and hold double the amount of carbon that is in the atmosphere (Canadell & Raupach 2008; FAO 2010b). This shows the important contribution of the forests in mitigating climate change through reducing atmospheric carbon; however, there is also significant risk of stored carbon being returned to the atmosphere through forest disturbance (Canadell & Raupach 2008). Deforestation and forest degradation contribute 10–25 % of total global emissions (Stern 2007; Van der Werf *et al.* 2009). Those emissions related to deforestation and forest degradation come mainly from human activities (Kasischke *et al.* 1995; Nepstad *et al.* 1999; Hurteau *et al.* 2008). This is mostly in developing countries where forests are used for economic development (Koop & Tole 2001; Ewers 2006). For example, in Nepal, the area of forests decreased by 1.7% per annum from 1978 to 1994. Shrub areas of Nepal is incresing from 4.7% in 1978/79 to 10.6 % in 1994 of country areas which shows that degradation is going on in some of the existing forests (FAO 1999).

2.2.2. Global forest management practices and community forestry

Clarity in ownership is an important factor in achieving the aim of sustainable forest management (Dudley *et al.* 2005; Jin & Sader 2006; Siry *et al.* 2005). At present, global forests are mainly under three ownership systems, namely public, private and community. The majority of forests are owned by government, followed by private (individual or company) and community (White & Martin 2002; FAO 2011;). Forest areas owned by government are generally larger in developed countries than in developing countries, while the opposite is the case for community owned forests which are larger in developing countries. Similarly, a larger proportion of private forests are in developed countries than in developing countries (Table 2.1). In the case of CFs, local communities are working collectively to manage their surrounding forests (Gilmour & Fisher 1991; Bray *et al.* 2005; Pagdee *et al.* 2006) through mutually agreed plans and decisions (Nurse & Malla 2006).

Table 2.1 Ownership of the global forests

Categories	Government (%)	Community (%)	Private form (%)
Global forest	77	11	12
Developing countries	71	22	7
Developed countries	81	3	16
Tropical countries	71	19	10

Source: White & Martin (2002)

All forests contribute to global climate change mitigation (Houghton 2005; Maraseni *et al.* 2005; Peichl & Arain 2007) although the quantity and trends of carbon sequestration capacity vary (Kasischke *et al.* 1995; Lambin 1999; Ayres 2000; Koop & Tole 2001; Pregitzer & Euskirchen 2004; Houghton 2005). A global study conducted in major forested countries found that a significant proportion of government managed forest areas have logging concessions, particularly in Canada, Democratic Republic of Congo, Central African Republic, Gabon, Equatorial Guinea, Malaysia, Cambodia and Indonesia (White & Martin 2002) indicating a possible risk of increasing deforestation and forest degradation. CF recognises the traditional forest resource use rights of local and indigenous communities who are living in areas surrounding forests and have a history of using forest resources for their basic needs (Arnold 1991; Nurse & Malla 2006). CF is expanding in developing countries (White & Martin 2002) and there are now more than 10% of global forests and over 22% forests in developing countries under this form of management (Nurse & Malla 2006). This proportion is likely to increase with the present global prioritisation of participatory forest management approaches which emphasise equity and livelihood needs, in line with the aims of decentralization, cost effective management, capacity of the local people to be a best manager and proximity to resources (Brown 1999 ; Gilmour 2003; Gilmour *et al.* 2004).

The concept of CF evolved in the 1970s with recognition of the interdependent relationship between local communties and forests with local communities using forest products for various needs including fodder, fuel, foods, timber and fibre (Davidar *et al.* 2008; Metz 1994). In Nepal, the Government allocates a certain area of national forest to an organized group of local communities who live around a forest and use forest products for their subsistence (Acharya 2002; Gilmour *et al.* 2004). After three decades of CF practices, Nepal has devolved forest management authority of more than 25% of its forested areas to 17,808 CFUGs involving more than 35% of the total population of the country (CFD/DoF 2013). Now, CFUGs are able to improve forest status and some of them have initiated to get economic benefits from sustainable harvesting of forest products (MFSC 2013).

2.2.3. Forestry sector in climate change mitigation policy

The scientific community has identified that the maximum allowable increment in mean global temperature of 2°C above the preindustrial level to minimise future climatic impacts (Meinshausen 2006; Randalls 2010) and that this is possible by limiting GHGs emissions to 550 ppmv (parts per million by volume) CO_2 equivalent (Randalls 2010). The UNFCCC agreed to develop a collaborative plan between developed and developing countries, linked to the sustainable development agenda (UNFCCC 2010). For this, the UNFCCC through the Kyoto protocol (1997) set emission reduction targets for industrialised countries and provided options to achieve the target by adopting three mechanisms; these are the Clean Development Mechanism (CDM), joint implementation and emissions trading (Kyoto-Protocol 1997).

The IPCC fifth assessment report (2014) clearly identifies the forestry sector as one of the key sectors responsible for GHG emissions (Victor *et al.* 2014) while conserving and reducing forest biomass loss can provide a relatively cheap form of climate change mitigation (Stern 2007). Therefore, forestry sector emissions were included in the UNFCCC, a key intergovernmental global body that facilitates discussions on global concerns and solutions related to climate change among parties, starting from the fifth Conference of Parties (CoP) (Kyoto-Protocol 1997) (Figure 2.2). The Kyoto Protocol (1997) included afforestation (plant and develop new forests on land where forests had not existed for a long period) and reforestation (plant and develop forests where forests had previously existed) project activities under the CDM mechanism. However there were few afforestation and reforestation (A/R) projects under the CDM mechanism with only 55 A/R projects of a total of 7,531 CDM projects registered with the UNFCCC by 2014 (UNFCCC 2014). This could be a result of the cumbersome process involved in getting a project registered under the CDM (Hayashi & Michaelowa 2007) and the comparatively long time needed for forestry projects to sequester a significant quantity of atmospheric CO_2.

Although natural forests and their role in mitigating climate change were not included in the CDM, deforestation and forest degradation of natural forests was highlighted as the main source of GHG emissions in developing countries (Gibbs *et al.* 2007) and global forest loss was recognised as massive in tropical countries including Brazil and Indonesia (Gibbs *et al.* 2007; Van der Werf *et al.* 2009). Costa Rica, Papua New Guinea and Central African Forest Commissions raised strong concerns about avoided deforestation at the 11th session of the Conference of Parties (COP 11) and requested consideration of avoided deforestation by the UNFCCC. However, provisions for rewarding countries which reduce deforestation and forest degradation were only considered after COP 13 (UNFCCC 2007).

Reducing emissions from deforestation and forest degradation (REDD) was included in the Bali Action Plan at COP 13 (UNFCCC 2007). The concept of reducing deforestation and forest degradation, conservation, sustainable management of the forests and enhancement of forest carbon (REDD+) was introduced in COP 14 in Poznan (2008) and agreed in COP 15 in Copenhagen (2009). Inception of the REDD+ was supported by pressure from countries associated with the Rainforest Alliance, countries of the African Forest Commission and the advice of UNFCCC's SBSTA. To put these decisions in practice, COP 15 encouraged developed countries to support developing countries for readiness and demonstration activities for REDD+.

While developing strategies and planning for the REDD+ is underway, the literature highlights a possible threat to biodiversity and the rights of local and indigenous communities (Angelsen 2009; Kanowski *et al.* 2011; Thompson *et al.* 2011). At the 16th COP in Cancun, parties agreed to develop appropriate guidelines for safeguarding these social and environmental principles while developing REDD+ projects in developing countries (UNFCCC 2011). The 19th COP adopted the 'Warsaw framework' to move forward on REDD+ which includes provisions for developing: (1) national and sub national level forest monitoring systems; (2) guidelines for safeguarding social and environmental benefits; and (3) financial and technical support for developing countries (UNFCCC 2014).

It is now already seven years after the REDD+ concept evolved which is coming through various discussions in different COPs at the UNFCCC (Figure 2.2).

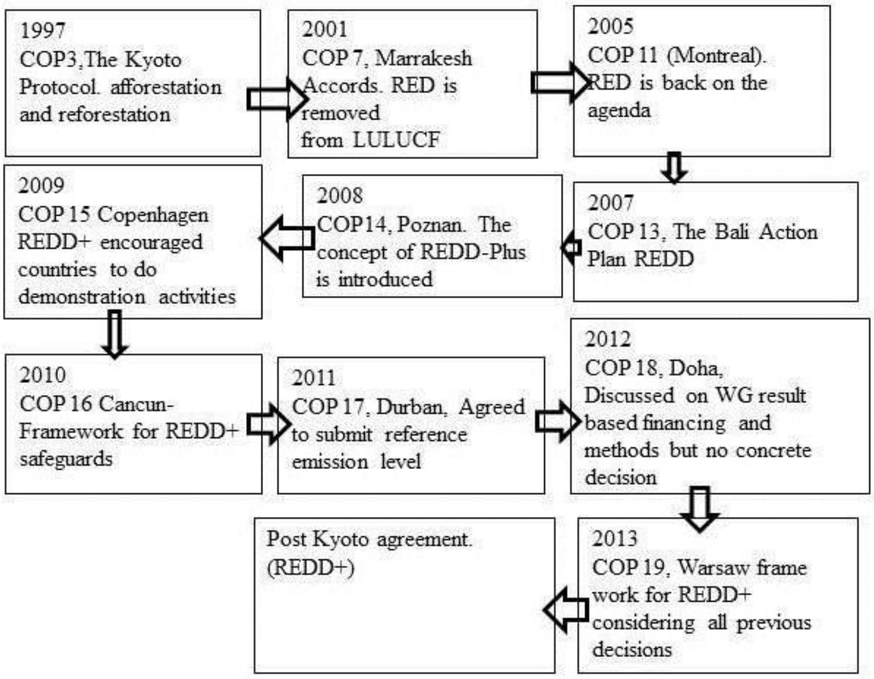


Figure 2.2 Development of the REDD+ mechanism in UNFCCC

(***Source*: UNFCCC websites:**
http://unfccc.int/resource/docs/convkp/kpeng.pdf; http://unfccc.int/land_use_and_climate_change/lulucf/items/3063.php; http://unfccc.int/meetings/montreal_nov_2005/meeting/6329/php/view/decisions.php; http://unfccc.int/resource/docs/2007/cop13/eng/06a01.pdf; http://unfccc.int/meetings/poznan_dec_2008/meeting/6314.php; http://unfccc.int/meetings/copenhagen_dec_2009/meeting/6295.php; http://unfccc.int/meetings/cancun_nov_2010/meeting/6266.php; http://unfccc.int/resource/docs/2011/cop17/eng/09a02.pdf; http://unfccc.int/resource/docs/2012/cop18/eng/08a01.pdf; and http://unfccc.int/key_steps/warsaw_outcomes/items/8006.php)

2.2.4. REDD+: introduction, challenges and opportunities

a) REDD+: an introduction

REDD+ is considered to be a relatively cost effective, easy and quick way to mitigate climate change (Clements 2010; Angelsen *et al.* 2012; Gardner *et al.* 2012). The market based mechanism is expected to incentivise developing countries to undertake forest management activities to enhance carbon stocks in forests. The REDD+ will be voluntary for any developing country which can participate and present a verifiable quantity of forest carbon enhancement (Gibbs *et al.* 2007). It must have additionality in emission reduction or sequestration with REDD+ project activities. The additionality means that quantity of reduced emissions or increased sequestration which would not have happened without the REDD+ project activity or at the business-as-usual scenario. It includes five forestry activities for reducing forestry related carbon emissions and increasing sequestration of atmospheric carbon in developing countries. These are: (1) reducing emissions from deforestation; (2) reducing emissions from forest degradation; (3) conservation of the forests; (4) sustainable management of forests; and (5) enhancement of forest carbon stocks (UNFCCC 2010; Angelsen *et al.* 2012). Brief descriptions of these activities follow.

<u>Reducing emissions from deforestation</u>: The Marrakesh accord defined deforestation as a direct human-induced conversion of forested land to non-forested land (Angelsen *et al.* 2008). Reducing deforestation is a primary aim of the REDD+ (de Jong *et al.* 2010). Government or forest owners should limit the conversion of forest areas to other land use systems from the reference forest area (UNFCCC 2007). The reference level of historical deforestation is estimated for projecting business-as-usual scenarios against which the reduction of deforestation is monitored for REDD+ outcome.

<u>Reducing emissions from forest degradation</u>: Forest degradation activity is a reduction of biomass stock and productivity of a forest. Forest cover in degraded forests is reduced from the reference level (Van der Werf *et al.* 2009). In REDD+, establishing baseline scenarios, developing a reference level and monitoring forest biomass degradation part is difficult compared to the deforestation situation (Herold & Skutsch 2011). Most forests face some sort of degradation due to human activities including CFs (GoN/MFSC/REDD-Cell 2014); however, levels of forest degradation can differ.

<u>Conservation of forests</u>: In the context of REDD+, the conservation of forests means conserving forests in as close to natural condition as possible. In this activity, maintaining the existing biomass stock of forests is expected to ensure the carbon sequestration capacity of forests (Herold & Skutsch 2011). In CFs, strict conservation without allowing people to harvest forest products may not be possible because the fundamental objective of CF is to improve forests and provide subsistence forest products to CFUGs (GoN 1993). If a CFUG has decided on strict conservation without arranged alternatives, that may either encourage leakage or deteriorate local people's socio-economic prospects, which would be against REDD+ concepts and UNFCCC agreements (Brown *et al.* 2008; UNFCCC 2011).

Sustainable management of forests: Sustainable management of forests means the conservation and sustainable use of forest resources without reducing existing productivity and biomass stock. This activity includes sustainable use practices (i.e. use within the limit of yield) that create zero or positive carbon balance in the long-run (Herold & Skutsch 2011).

Enhancement of forest carbon stocks: The enhancement of forest carbon stocks is also a key part of the REDD+ mechanism. For this, activities which ensure reductions in the extraction of forest resources, plantation activities, the promotion of alternative sources of forest products and reduce pressure on forests can be designed and implemented (Geist & Lambin 2002; Nagendra 2007).

b) Challenges and opportunities on REDD+

Although, the REDD+ is a promising mechanism, the design and implementation of this mechanism is challenging (Minang & van Noordwijk 2013). It may require changes to existing historical practices and the building of political consensus between key actors in policy arenas to achieve multilevel coordination (from global to local communities) and manage complex flows of information and payments in the context of large future uncertainties about climate mitigation regimes while ensuring supply to meet strong immediate demands for food, fuel and fibre (Angelsen *et al.* 2012). The REDD+ has a supposition of win-win policy frameworks that help to attain dual goals of reduction in GHG emissions and reduction of poverty in developing countries (Angelsen *et al.* 2009). For effective implementation, appropriate REDD+ policy, projects and implementation strategies may be needed. However there are various challenges indicated and issues raised in global discussions and the literature which need to be addressed. Key issues and challenges associated with REDD+ are discussed below:

Technical challenges in developing a credible MRV mechanism: Measurement, Reporting and Verification (MRV) of the REDD+ project performance is important to show carbon sequestration performance and to claim credits. Making a credible MRV mechanism considering transparency, accountability and sustainability is an important issue for the REDD+ framework (Angelsen *et al.* 2009). The use of external experts in the MRV process is possible, but may increase the costs and therefore the price of carbon credits in REDD+ schemes. On the other hand, the full or partial participation of local people in the MRV process can be cost effective, transparent and sustainable (Rist *et al.* 2010; Danielsen *et al.* 2011); therefore the potential of using locally based monitoring systems in REDD+ is emphasised (Skutsch 2005; Danielsen *et al.* 2011). Participatory monitoring may be more suited to the CF system as local communities that are managing a forest may be involved in forest resource monitoring (Ojha *et al.* 2009). However, an appropriate verification mechanism would need to be developed.

During design phase of the REDD+ project, a baseline scenario and a historical Reference Emission Level (REL) of deforestation and forest degradation of the country is identified on the basis of historical data (Herold & Skutsch 2011). In REDD+ projects, REL and change in carbon credits is estimated and verified to make the carbon credit marketable.

Developing equitable benefit sharing mechanism: Multiple stakeholders are involving in forest management in developing countries including government agencies, communities and the private sector (FAO 2010b). The combined efforts of all stakeholders in REDD+ projects are expected to generate carbon credits from their forest management. Creating an environment by involving all stakeholders including local communities, accounting contributions of rural people and designing an equitable benefit distribution without promoting perverse incentives are important for an effective REDD+ mechanism (Lindhjem *et al.* 2011).

Social and environmental safeguards: The possible exclusion of local people and indigenous people from the decision making process of the REDD+ projects was raised in UNFCCC's COP 16 and an agreement was made for social and environmental safeguards (UNFCCC 2011). It can however be difficult to secure the rights of local communities and indigenous people in the REDD+ process (Singh 2008; Angelsen *et al.* 2009; Karousakis 2009; Grainger *et al.* 2009; Ghazoul *et al.* 2010; Springate-Baginski *et al.* 2010; Corbera & Schroeder 2011; Lyster 2011; Thompson *et al.* 2011). This is important because a huge number (827 million) of people living in developing countries are hungry with 14.3% of the global population undernourished (FAO 2013). Many local and indigenous people living in these countries have long relied on forest resources for their livelihood (White & Martin 2002). This dependency has been recognised in CF programme in which local communities are engaged in forest improvement to fulfil household level of forest products needed.

As forest ecosystems are rich in terrestrial biodiversity in comparison to other ecosystems (CBD 2001), CF has been contributing to improved forest ecosystem condition (Dev *et al.* 2003; Thoms 2008). However poor people are motivated to generate income from forest management (Subedi 2006) and therefore their management can promote certain tree types which have higher carbon growth potential. This may result in the loss of biodiversity in these forests.

Although CF is contributing both to improved livelihoods of poor communities and condition of forests, REDD+ carbon oriented forestry practices may impact upon livelihood benefits and environmental conservation. If REDD+ projects do not consider the livelihood needs of local communities during project design and implementation, they may create a scarcity of forest resources to those communities (Chhatre and Agrawal 2009; Caplow *et al.* 2011). Similarly, the REDD+ project with carbon-oriented activities may promote limited fast-growing species without conserving multiple species and ecosystems. Maintaining multiple species is important for securing biodiversity benefits in abiding by the Convention on Bio Diversity (CBD 1992). Species-focused management will create instability within local societies and biodiversity loss which may ultimately lead to adverse outcomes for the REDD+ activities. Therefore safeguarding both community livelihood (social safeguard) benefits and biodiversity (environmental safeguard) is important for REDD+ projects.

Addressing possible leakage and non-permanence: Carbon leakage in REDD+ projects (i.e. conserving or increasing carbon stock in project areas by shifting source of biomass extraction to outside project areas) may lead to an increase in emissions

(Phelps *et al.* 2010; Olander *et al.* 2012). This is possible in CF if communities are encouraged to avoid extraction of forest products while no alternatives to forest products are provided. Leakage issues could be addressed by considering potential emissions displacement, implementing possible activities and adopting proper leakage monitoring. Similarly, securing the permanency or irreversibility of emissions reductions for a REDD+ project is also a challenge (Angelsen 2009). Warranting tenure rights, providing alternative sources of forest products and benefits with increasingly less dependency on forests will ensure long-term emissions reduction (Angensen *et al.* 2008; Phelps *et al.* 2010). If governments take back forests from CFUGs or communities cannot get adequate monetary benefits from REDD+, extraction of forest products may increase again to similar levels to those experienced before the REDD+ activities.

Besides the above mentioned challenges, REDD+ has several associated opportunities for participating countries particularly in securing poverty reduction, biodiversity and other environmental co-benefits in developing countries (Huettner 2012). Key opportunities of REDD+ are:

- The REDD+ mechanism has potential to provide significant new opportunities for developing countries to receive funding for forest restoration projects and programs (Alexander *et al.* 2011).
- Carbon credits may be generated by reducing forestry sector GHG emissions and increasing the capacity of forests to sequester additional CO_2 in developing countries. Since GHG emissions in developing countries are low, these countries should be able to sell carbon units gained from forest management and get monetary benefits from high emissions countries (Kyoto-Protocol 1997).
- REDD+ mechanisms will provide opportunities to developed countries to offset their emissions in developing countries. This mechanism will help to achieve their commitments and emission reduction targets by purchasing carbon credits from developing countries (Phelps *et al.* 2010).
- REDD+ can reverse degradation in forests and deforested areas, and increase vegetation cover in denuded areas (Laurance 2008).
- REDD+ can generate various co-benefits or non-carbon benefits particularly conservation of biodiversity if there are multiple species promotion strategies (Kanowski *et al.* 2005; Grainger *et al.* 2009; Karousakis 2009) and enhance other ecosystem services (Millennium Ecosystem Assessment 2003).

c) Present REDD+ projects in practices

Establishment of a mechanism and arrangements which enable the mobilisation of financial resources from developed countries was a key emphasis in the Copenhagen Accord (UNFCCC 2009). After Copenhagen, different funding schemes such as the World Bank funded Forest Carbon Partnership Facility (FCPF), UN-REDD and other bilateral approaches were initiated (Miles 2010).

The FCPF and UN-REDD programs are major funding schemes to support pilot REDD+ projects. Under the FCPF programme, 44 developing countries encompassing 17 in Africa, 16 in Latin America, and 11 in the Asia-Pacific region are carrying out readiness activities for REDD+. The FCPF has two separate but complementary funding mechanisms, namely the Readiness Fund (preparation for

REDD+) and the Carbon Fund (to achieve its strategic objectives). The FCPF has raised about US$648 million including US$258 million for the Readiness Fund and US$390 million for the Carbon Fund (FCPF/World-Bank 2013). Similarly, the UN-REDD programme supports 53 partner countries across Africa, Asia-Pacific, Latin America and the Caribbean directly, through funding, or indirectly, by helping them to participate in meetings and discussion forums. By June 2014, total funding for these two streams was US$195.7 million (UN-REDD 2014). In addition, there are several projects operating under bilateral funding schemes including USAID and NORAD. These projects focus on raising awareness of REDD+ and climate change issues and the REDD+ pilot projects are designing and implementing awareness raising and capacity building of local communities as important priority activities.

By October 2009, there were more than 79 REDD+ readiness projects and over 100 REDD+ demonstration projects operating in 64 developing countries (Cerbu *et al.* 2011). These numbers should continue to increase given continuing focus in the global negotiation process and funding support from donors. Readiness projects include policy formation, establishment of REL, institution building and organisational capacity building in developing nations. Demonstration project activities include designing projects, identifying the drivers responsible for deforestation and forest degradation and appropriate activities to address those drivers. At the pilot stage, most of the REDD+ projects were initiated in those countries which had higher deforestation rates, no significant socio-political issues and better governance. Consequently, fewer REDD+ projects are to be found in Africa while more have been instigated in Brazil, Indonesia and Cambodia (Cerbu *et al.* 2011).

d) REDD+ in community based forest management

With decades of experience, local communities have developed a system for planning, managing and harvesting forest resources and receiving socio-economic benefits in CF (McDermott & Schreckenberg 2009; MFSC 2013). Many studies have highlighted a possible linkage between CF and REDD+ mechanism and suggested that the learnings and existing institutional set up of CFs be used in the upcoming REDD+ mechanism (Agrawal & Angelsen 2009; Hayes & Persha 2010; Fry 2011; Larson 2011; Alcorn 2014).

Since CF can contribute to mitigating climate change (Maraseni *et al.* 2005), these forests will be important in REDD+ incentive mechanisms in the future. While they were mainly within country, there were Payment for Ecosystem Services (PES) mechanisms functioning in Latin America before the UNFCCC agreement on 2007 (Sills *et al.* 2009; Alcorn 2014). These local PES mechanisms involved local communities in the maintenance of multiple services through the reduction of deforestation and forest degradation. These mechanisms was found contextual (both beneficial as well as not beneficial) from a pro-poor perspective (Grieg-Gran *et al.* 2005). As previously noted, while various pilot projects were initiated after the REDD+ concepts were agreed in the UNFCCC (2007), there is limited literature available on the lessons derived from the pilot REDD+ mechanism in CFs. There are several unanswered questions, particularly: Are all CFs contributing similarly to CO_2 emissions reduction? What is the potential carbon stock increment in existing CFs?

What key factors influence carbon stock changes in CFs? How much additional community effort (in term of monetary value) is used for REDD+ in CFs? Answers to these questions may help to design an effective REDD+ projects in CFs.

After inception of the REDD+ concept in global climate change discussions, the government of Nepal facilitated national agencies to initiate pilot activities and a collaborative project was initiated in three watersheds covering *S. robusta* mixed broadleaf forests at lower altitude areas to *Rhododendron-Quercus* forest at high altitudes. This pilot project covers 105 CFs and is jointly implemented by the International Centre for Integrated Mountain Development (ICIMOD), Asia Network for Sustainable Agriculture and Bioresources (ANSAB) and Federation of Community Forestry Users Nepal (FECOFUN) with financial support from 2009-2013 from the Norwegian Agency for Development Cooperation (NORAD). The project implemented various activities including alternative energy promotion (biogas, improved cooking stock), training for appropriate silviculture operation, fire control activities and plantation activities to foster biomass carbon stock (ANSAB/ICIMOD/FECOFUN 2013). These projects activities potentially altered community forest management practices and carbon stock in forests. While the carbon stock in forests has changed (ANSAB/ICIMOD/FECOFUN 2013), the drivers of the change, including the role of dominant species in the differences observed, are unclear. Understanding this will help in raising awareness about potential carbon stock changes and enable future REDD+ projects and policies to focus on the key factors influencing carbon stock change. Moreover, there is little clarity about the potential for carbon growth in CFs and trade-offs of communities' present benefits for REDD+ carbon benefits. For REDD+ projects to make a long term contribution to carbon sequestration and community benefit, local communities may need to receive proper compensation for their changed behavior and additional efforts made for the REDD+ mechanism. Local forest dependent people are poor, therefore the project should emphasis the need to return higher benefits to them (Grieg-Gran *et al.* 2005; Alcorn 2014).

2.3. Carbon pools and carbon pool measurement in community forests

2.3.1. Carbon pools in CF

Vegetation removes carbon dioxide from the atmosphere through the natural process of photosynthesis and stores the carbon (C) in leaves, branches, stems, bark and roots (Johnson & Coburn 2010). Living biomass in the forests sequesters atmospheric carbon dioxide ($CO_{2)}$ while dead wood, litter and soil store carbon. Carbon pools in forests are grouped into three major types, namely: (1) biomass (above-ground and below-ground biomass); (2) dead organic matter (dead wood, fallen twigs and leaf litter); and (3) soil organic matter (MacDicken 1997; Houghton 2005; IPCC 2006). All three components of the carbon pool can be considered for carbon accounting in CFs and the extent to which community activities reduce these pools, thereby affecting carbon stock, can be measured. Most CFUGs collect dead branches and leaf litter (Metz 1994; Maskey *et al.* 2006) from CFs and it can be assumed that communities leave little of this biomass in the forests for decomposition and formation of soil carbon. Therefore, it is unlikely that CF would change soil organic carbon (SOC) in the short time period because the accumulation of dead and dry matter in forests and changes in land use practices are the main causes for SOC change (Laurance *et al.* 1999; Guo & Gifford 2002). Therefore it can be assumed that there is a constant or negligible change in SOC in CFs during the three year period of this study.

2.3.2. Carbon pools measurement methods

In REDD+ mechanism, baseline scenarios of carbon in forests without REDD+ initiatives and possible carbon stock added in forests after the REDD+ project activities is estimated (Eckert *et al.* 2011). Therefore estimation of REL is key step for carbon projects which is defined by analysing historical deforestation and forest degradation data of the project areas or a country (Herold&Skutsch 2011; Pelletier *et al.* 2011). The performance of the REDD+ project is estimated from a verifiable change in emissions over the REL (Pelletier *et al.* 2011).

Two types of approaches namely gain-loss and stock different are suggested by IPCC (2006) to estimate carbon stock change in projects. Gain-loss methods estimate annual change in biomass from gain or increment in biomass stock in the forests (i.e. growth) and loss or removal of biomass from the forests (i.e. extraction of biomass). Similarly, stock difference method estimates changes in biomass between two definite points of measurements. The biomass gain-loss method is applicable for all tiers (i.e. tire 1 method- is more general and use global or continental data; tire 2 method - use country specific data and tire 3 method- use forest specific data) while stock-difference method is more suited to tiers 2 and 3. This is because the stock-difference method provides more reliable estimates in case of large increases or decreases of biomass and accurate forest inventories are carried out (IPCC 2006).

Stock difference methods can be better in forest carbon monitoring which gives changes between stock at baseline and after the REDD+ project activities. To estimate carbon stock in forests at certain point, most of the studies have used either remote sensing (Steininger 2000; Dong *et al.* 2003; Basuki *et al.* 2009; Eva *et al.* 2010) or field inventory (Haripriya 2000; Dieter & Elsasser 2002; Mani & Parthasarathy 2009; Alves *et al.* 2010; Sharma *et al.* 2010). However, field measurement involving local communities is taken as a better approach to estimate biomass carbon in CFs at project level (Karky & Skutsch 2010). This is because, communities may trust the data generated by field inventory with their participation and local people involvements reduces costs of inventory (Karky & Skutsch 2010). In field inventory, measurement of various carbon pools i.e. litter and herbs, saplings and trees is done by establishing random plots in the forests (MacDicken 1997; Subedi *et al.* 2010).

2.4. Factors affecting carbon stock changes in CF

Two terminologies, deforestation and forest degradation, are commonly used in discussing forestry sector emissions. “Deforestation” is the conversion of forest to another land use or long-term reduction of tree canopy cover below a 10% threshold (FAO 2001). The Marrakesh Accord further defined deforestation thresholds between 10 to 30% of forest cover (Boyd & Schipper 2002). Similarly, “forest degradation” is defined as a process that leads to a temporary or permanent deterioration in stocking rates (Grainger 1993; Corbera *et al.* 2010). This can occur in forests while overall forest canopy cover is still above deforestation threshold levels (10–30%).

Either proximate (visible) or underlying are responsible for deforestation and forest degradation in developing countries (Lambin *et al.* 2001; Geist & Lambin 2002). Most of these factors are site specific (Scrieciu 2007) and might be different according to countries and locations within country (Bhattarai & Hammig 2001). Identifying possible drivers for a particular country and specific forest management systems can facilitate the design, planning and effective implementation of REDD+ projects.

Although all CFs in a country follow the same guiding principles and policy provisions, there is also a possibility that a range of forest management outcomes will be achieved across the individual CFs (Thompson *et al.* 1990; Baral & Subedi 2000; Pokharel 2011). There might be various factors driving these differences which are important to know for designing and implementing REDD+ projects in CFs. As a key objective of REDD+ is to generate additional carbon benefits through providing incentives (Angelsen 2009), CFUGs may change the subsistence use aims of CFs, influencing CFs to change their use practices and forest management priorities to benefit from the REDD+ mechanism. Although previous studies identify different success factors for CFs, including: (1) biophysical and/or resources; (2) social-economic; and, (3) socio-political (Ostrom 1990; Gibson *et al.* 2000; Agrawal & Ostrom 2001; Varughese & Ostrom 2001; Foley *et al.* 2005; Agrawal & Angelsen 2009), there is limited knowledge about success factors for REDD+. The factors influencing the success of CFs may or may not work in the same way in REDD+ project in CFs. However, those factors could provide a basis on which to assess ongoing REDD+ projects. Similarly, drivers identified for deforestation and forest degradation in government managed forests with different socio-political contexts may be different than those operating in CFs. For example, the main drivers of deforestation and forest degradation in tropical countries are reported to be infrastructure development, agriculture expansion, wood extraction, forest fire, demographic, forest quantity harvest, income, proximity, policy and institutional differences (Cochrane & Schulze 1999; Pahari & Murai 1999; Bahuguna 2000; Blackmore & Vitousek 2000; Roy 2003; Grau *et al.* 2005; Balch *et al.* 2011; IPCC 2014); these may not be similarly important for CFs in Nepal. The previous studies cover global or regional levels, while project specific studies are limited, particularly in relation to CFs. However, these studies can provide a useful knowledge base for the design of appropriate activities for REDD+ projects which address these factors and increase carbon stock in forests. Possible factors are discussed below.

2.4.1. Possible biophysical factors

Brief descriptions of biophysical factors which might play a role in carbon enhancement in CF are given below.

a. Canopy cover differences: Forest canopy is one of key determinants that affects the growth and survival of plants (Smith *et al.* 1997; D'Amato *et al.* 2011) and so can make significant difference to the quantity of carbon stock in CFs. Canopy cover creates different micro-climates in forests by obstructing the penetration of light and precipitation to the forest floor thereby influencing tree growth (Jackson

1994; Khanna 2004). If a species is a light demander, it may not grow well under the closed canopy of a forest while the opposite is the case for shade bearer species (Khanna 2004). In general, very dense forests may not allow all trees to reach their potential stem diameter due to high competition for space, minerals and food (Smith *et al.* 1997; D'Amato *et al.* 2011). In the case of CFs, user communities carry out different forest management activities which may create different crown densities, thereby affecting the quantity of biomass carbon.

b. Altitudinal variation: Altitude affects the distribution of different vegetation types in CFs (Jackson 1994; Vetaas & Grytnes 2002). However, there are contradictory findings regarding biomass carbon quantity variations along altitude gradients. A study in Brazil found increasing biomass with increasing altitude in tropical moist forests (Alves *et al.* 2010) while biomass was higher in lower altitude than higher altitude forests in the Himalaya region (Singh *et al.* 1994). However, forest products such as fuel wood use practices in CFs is different with altitude in Nepal (FAO 1999), which may affect biomass carbon stocks in forests. It would helpful in the design of REDD+ projects and benefit sharing mechanisms if possible relationship between carbon stock and altitudes in CFs were known.

c. Climatic patterns: Intensity of rainfall, drought and temperature affect seed production, germination and establishment of seedlings in forests (Everham III *et al.* 1996). More rainfall, short duration of drought and appropriate temperatures help to germinate more seedlings and support their establishment and physiological activity (Yang *et al.* 2006). Weather affects photosynthesis processes and therefore biomass enhancement in forests in their natural state. However, different vegetation types are adapted to different climatic patterns (Jackson 1994). In the short term, climatic patterns may not vary greatly and climate change may have negligible effects on species growth.

d. Dominant tree species in forests: Many studies carried out in government managed forests and protected areas have found that biomass carbon stocks in forests are affected by dominant vegetation types (Lodhiyal & Lodhiyal 2003; Rossi *et al.* 2009; Tan *et al.* 2011). However, given the different management regime, these findings need to be verified for CFs. There are various dominant vegetation type forests found in Nepal and these forests are also under community management (GON 2002). These forests differ in growth characteristics and wood density, both of which affect biomass carbon (Kauppi *et al.* 1992; Jandl *et al.* 2007). In global classification systems, these forests can be classified into tropical, sub-tropical, lower temperate, upper temperate, subalpine and alpine forests (Schmitt *et al.* 2009). Brief descriptions of the forest types in Nepal are given below (Jackson 1994):

   - *Shorea robusta* forests: This forest type is close to the tropical forests of global classification systems (Woo *et al.* 1991). *S. robusta* is a large tree up to 45 m height. This is a slow growing tree species; however, it can grow quickly at the younger stages under favourable conditions. *S. robusta* forest is dominant in Terai low land, including the Siwalik hills, and is distributed up to 1,500 m asl (metres above sea level). It is deciduous (leaves fall for a short time) and a light demander. Seedlings of *S. robusta* are susceptible to dieback if there is frequent frost, drought and/or fire. This is a popular timber tree and highly preferred for building houses in the country (Troup 1921; Jackson 1994).

- Mixed broadleaf forests: Similar to *S. robusta* forests, mixed broadleaf forests are close to the tropical forests in global classification. This forest type includes species such as *Lagerstroemia parviflora* (Botdhairo), *Terminalia spp, Anogeissus latifolia* (Bajhi*), Dalbergia sissoo* and *Syzygium cumini* (Jamun). *L. parviflora* is a large, deciduous, light-demanding tree which is distributed from Terai and Bhabar zones in Terai to about 1,200 m altitude. It is not affected by browsing by cattle and able to recover quickly after fire. As with *S. robusta, L. parviflora* is a valuable timber tree. *S.cumini* (Jamun) is a fairly fast growing species which is found in wide ranges from Terai to 1,600m. *A. latifolia* (Bajhi) occurs from Terai to 1,700 m elevation, has a moderate growth rate and is unpalatable to livestock and not damaged by browsing. *Dalbergia sissoo* is a fast growing strong light demanding tree found up to 1,500 m asl and *Terminalia* spp is a light demander and moderate growth tree found up to 1,100 m asl (Troup 1921; Jackson 1994).

- *Schima-Castanopsis* forests: These forests are more similar to the subtropical category in global classifications occurring in areas with a comparatively colder climate than tropical forests but with minimum temperature greater than those experienced in temperate climates (Woo *et al.* 1991). *Schima wallichi* is a large tree with a moderately shade-tolerant character which is generally found between 900 and 2,000 m asl together with *Castanopsis* species. There are three *Castanopsis* species found in different distribution ranges; *Castanopsis indica,* between 1,200 and 2,900 m asl, *Castanopsis hystrix* between 1,000 and 2,500 m asl and *Castanopsis tribuloides* between 450 and 2,300 m asl. These species are palatable and used as fodder for livestock (Boojh & Ramakrishnan 1983; Jackson 1994).

- Pine forests: Similar to *Schima-Castanopsis* forest, pine forest is closer to the sub-tropical forest category. *Pinus roxburghii* (occurring from 900–1,950 m asl)*, Pinus walichiana* (from 1,800–3,600 m asl*),* planted *Pinus patula* (from 1,500–2,500 m asl) and *Tsuga Dumosa* (from 2,100–3,600 m asl) are the major species found in this category. Pine trees are not palatable to cattle and are used for timber but they are soft and have lower market values than *S. robusta* (Jackson 1994).

- *Rhododendron-Quercus* forests: This forest type is closer to temperate forests and is found in areas experiencing a cold climate and covered by snow at certain times of the year. This forest is composed of three different tree types, *Rhododendron*, *Quercus* and *Lyonia* species. *Rhododendron* species grow from 1,500 to 3,300 m asl. They reach 15 m in height and the flower is used to make a pickle. *Quercus* species are generally found between 1,700 and 3,800 m asl and are used as fodder. *Lyonia ovalifolia* is a deciduous shrub and occurs from 1,300 to 3,300 m asl (Jackson 1994; Singh *et al.* 2003)

e. Age of the forest stands: As vegetation exhibits a sigmoidal growth curve (Weiner & Thomas 2001), there is increasing carbon stock found in forests with age (Lodhiyal & Lodhiyal 2003). However, communities manage and use forest resources in CF systems and CFs could be non-uniform by age category. Therefore both carbon stock and the age of forest stands in CFs could differ in terms of the natural sigmoidal growth pattern. In addition, this relationship has not been verified for all vegetation types. On the other hand, young forests have higher growth rates and capacity to sequester biomass carbon (Pregitzer & Euskirchen 2004; Bradford & Kastendick 2010) which may affect carbon benefits in a CF. Therefore, the age of forest stands could be one factor to be considered while designing and implementing the REDD+ project in CFs.

2.4.2. Possible socio-economic factors

Various socio-economic factors which have been shown to influence carbon enhancement in forests may or may not be applicable in CFs. Possible factors include:

a. Size of forests (Per capita forests available in individual CF): The size of CFs in Nepal range from less than 1 ha to over 2,500 ha (CFD/DoF 2013). Per capita forest allocation is listed as a success factor for CF (Agrawal & Angelsen 2009) and may influence carbon stock changes in CFs. Previous studies highlighted that the larger the per capita forest area available, the higher the possibility of success of CF (Agrawal & Angelsen 2009). However, this may not be true in all cases as communities may take greater care of a forest if it is smaller but management is linked to incentives. It has been reported that communities are conserving forests where there is a link with income (Subedi 2006). Clarity about the effects of per capita forest area on carbon stock and change in carbon stock in CFs is lacking in the existing literature.

b. Population growth: The relationship between the status of forests and population growth accords with Malthus' theory which makes three assumptions: (1) that food is a limiting factor for human populations; (2) that populations grow geometrically; and (3) that the land required to feed a growing population increases in a linear way (Seidl & Tisdell 1999). A growing population demands food which cannot be sufficiently derived from existing agricultural land, and this need is met by expansion of forests converted to arable land. However, the Malthus theory was developed in the 18th and 19th century and the present context is different. Now population growth control techniques are adopted all over the world (Robinson & Ross 2007) and appropriate technologies to increase agricultural production have been developed and applied (Lal 2006) that may be changing the assumptions on which Malthus theory is based. Ives and Messerli (1989) identified population pressure is main cause of deforestation in the Hill areas of Nepal. This was found in other literatures as well (Armenteras *et al.* 2006, Pahari & Murai 1999) but the relationship between population growth and deforestation trends may be weaker now where social, cultural, political and economic aspects of countries play a major role (Mather & Needle 2000). Therefore, we can assume that the relationship between people, agriculture and forests in CFs are context specific and this needs to be considered while designing REDD+ projects.

c. Caste variations: In Nepal, there are 125 different caste groups (CBS 2011b) which has created a social hierarchy within villages. In the social hierarchy, these castes come under Brahmin, Chhetri, Ethnic Groups and Dalit (Gurung 2003; Lynn *et al.* 2008), each of which may have different cultural and forest product needs. These diverse people are living in a village and organizing as a CFUG for the management of a forest (CFD/DoF 2009). Earlier research findings indicate that highly heterogeneous groups cannot make consensus decisions and implement those decisions (Blair 1996) thereby affecting forest management outcomes. However, this finding was opposed by Varughese and Ostrom (2001) who found no relationship between heterogeneity and forest improvement in CFs. Since carbon stock is a new product with likely benefits and opportunities, CFUGs may have changed existing practices including decision making processes. However, there are limited studies regarding the possible effect of community heterogeneity on carbon stock changes in CFs.

d. Accessibility of forests: There is no clarity about whether access to markets (distance from forest to road) and access to forests (distance from settlement to forests) affect biomass cabon in CFs. Close location (i.e. high accessibility to markets from road connections) increases deforestation (Angelsen & Kaimowitz 1999). This is because market demands for timber encourage local people to harvest more from forests. However, there is the opposite finding also that access to market helps to increase biomass carbon in forests by providing jobs to villagers and facilitating the adoption of alternative energy sources thereby reducing pressure on forests (Chhatre & Agrawal 2009). Similarly, settlement proximity to forests can have both positive and negative effects on biomass carbon. People can harvest more if the forest is located close to their house (Laurance *et al.* 2006), reducing biomass carbon. But this is less likely in the case of CFs where local communities aim to improve forests with shared goals and collective action (Ostrom 1990 and 1999) that can be effectively applied in nearby forests.

e. Forest management practices: Management practices can help to differ carbon stocks in forests (Dixon 1997; Foley *et al.* 2005; Hoover & Stout 2007; Harmon *et al.* 2009). Silvicultural operations (i.e. thinning, pruning, weeding, and cleaning) and protecting forests from disturbances (i.e. illegal harvesting, grazing and forest fire) are major forest management practices which may affect biomass growth (Thompson *et al.*1990) and also CO_2 emission/sequestration rates. Thinning frequencies in forest may help to increase the carbon sequestration rate because forest stands with regular thinning have higher growing stock compared to stands which are clear-cut on short rotations (Khanna 2004) and undisturbed old growth forests (Thornley & Cannell 2000; Harmon *et al.*2009). However, there is evidence for reduced aboveground carbon in thinned stands compared to un-thinned stands (Chiang *et al.* 2008; Campbell *et al.* 2009). Despite these insights, empirical evaluations of CF practices and outcomes are lacking (Hoover & Stout 2007) therefore forest management practice change for the REDD+ and carbon benefits needs to be evaluated.

f. Recurrence of forest fire (anthropogenic fire): Frequency of forest fire is considered an important factor that can affect forest carbon stock in CFs. Forest fire releases not only stored carbon from forests but also damages germination capacity and increases the mortality of trees and seedling (Arthur *et al.* 1998; Barlow *et al.* 2003). Moreover, forest fire damages the overall productivity of forests (Mehta 1996). A study conducted in east Amazon found that the unburned areas had stored 256 Mg/ha of living biomass whereas only 24 Mg/ha was stored in burned areas (Cochrane & Schulze 1999). However, if the fire is controlled and prescribed, it can be helpful in improving forests (D'Antonio 2000). Therefore, fire might play a role in carbon stock changes in CF; therefore it could be important to know about the incidence of fire and possible effects on carbon stocks in CFs.

g. Extraction of forest products: Illegal harvesting of trees for timber is considered a main driver of deforestation (Geist & Lambin 2002). Existing studies related to forests products extraction and deforestation cover mostly government managed tropical forests (Barbier & Rauscher 1994; Barbier *et al.* 1995). In CFs where local communities are guarding against illegal harvesting this may not be a problem. This is because communities are managing forests and operating management activities according to their own decisions (Gilmour & Fisher 1991; Schlager & Ostrom 1992; Acharya & Gentle 2006). In CFs, there is provision for sustainable harvesting of forest products by keeping the harvested quantity below the level of incremental increase in the forests (CFD/DoF 2009). As minimizing the harvesting of forest products is critical to maximizing the aboveground carbon stock (Harmon *et al.* 2009; Nunery & Keeton 2010), knowledge about the harvesting behaviours of communities and the quantity of extraction can be important in the design of REDD+ projects in CFs.

h. Grazing: Grazing is also an important factor which plays a role in forest carbon sequestration (Vinton *et al.* 1993) particularly by reducing biomass in the forest (Blackmore & Vitousek 2000). A study conducted in natural pasture land in Africa concluded that grazing land subject to heavy grazing pressure has significantly reduced vegetative cover and biomass yield, particularly on steep slopes (Mwendera *et al.* 1997). However, the opposite finding has also been reported: that controlled grazing aids forest improvement (Smith *et al.* 1997; D'Amato *et al.* 2011). In CFs, there may be different grazing provisions and practices which may affect carbon stock. Possible relationships between grazing practices and carbon stock need to be analysed when designing REDD+ projects.

i. Average household level private agriculture land holding in CFUGs: Forests are the main source of fuel wood and fodder in rural areas (Adhikari *et al.* 2004). The collection by local communities of dry biomass from the forests for fuel wood is common practice in Nepal where 77% of household energy demand is fulfilled from forests (WECS 2010). However, while people collect fuel wood from nearby forests (Metz 1990), it is possible to grow trees on private land to reduce the pressure on CFs. Therefore, the average agriculture land holding size and alternative sources of fodder, grasses and timber may play a role in increasing carbon stocks.

j. Average household level livestock size in CFUGs: The relationship between livestock numbers in households and forest conservation status was found to be both positive and negative in different literatures. A study found that deforestation has increased the scarcity of fodder and grass supply from forests and therefore communities have reduced numbers of livestock (Barraclough & Ghimire 1995). However, another study found that the conservation of forests has reduced fodder and grass supply and reduced community livestock numbers (Dhakal *et al.* 2005). Given these contradictory findings, analysis of livestock numbers and effects on carbon stock in CFs is needed.

k. Alternative energy use in CFUGs: Wood is a major source of global energy supply. Global production and use of round wood was about 3300 (10^6) m^3 in 1999 and 55% of wood is used for fuel (Parikka 2004). Fuel wood use is comparatively high in developing countries i.e total 90% of global fuel wood consumption (Parikka 2004). In Nepal, over 80% of the country's energy is derived from fuel wood (WHO 2006). Biogas (cattle dung is used) and liquefied petroleum gas (LPG) are the main alternative household energy sources used at the household level in Nepal (WECS 2010). To reduce the use of fuel wood, improved cooking stoves (ICS) have also been designed and promoted in communities because traditional cooking stoves consume 30–40% more firewood (Bhattacharya *et al.* 2000) than ICSs (Dhakal & Raut 2010). Theoretically, the use of alternative energy sources should increase carbon stock in CFs but this need to be analysed.

2.4.3. Possible political factors

a. International and national policy: International and national policy mechanisms are the key to changing carbon stocks in forests. Decisions of UNFCCC Conference of Parties (CoP) sessions influence the number of forest carbon projects in developing countries. Based on conference decisions regarding the incentive provisions of REDD+, developing countries have proposed different strategies and policies for biomass carbon increments in forests (FCPF/World-Bank 2013). As the national REDD+ strategy is common guiding document, it could have similar provision for a particular forest management system in the country such that the policy itself would not differentiate between carbon stocks of CFs. Therefore the policy factor was not included in analysis of carbon stock changes in CFs.

b. Tenure issue of forests: Clarity on the tenure of forests is important in the REDD+ mechanism; therefore clarifying tenure must be an initial step in the REDD+ project. If forests are under the ownership of multiple stakeholders, they may have less effective management than those with clear community ownership (Duchelle *et al.* 2014; Dunlop 2009). Besides tenure clarity, economic benefit to local communities is also important in making the REDD+ effective (Resosudarmo *et al.* 2014). However, CF in Nepal has clear policy provision that ownership of forest products lies with the community while ownership of land lies with government (GoN 1993). Carbon rights are associated with land tenure; hence it is important to clarify this issue to ensure a fair mechanism when a CF enters the performance–based market (Karsenty *et al.* 2014).

c. Governance mechanism of CFUG: Good policy, appropriate institutional structure and deliberative decision making processes are important aspects in forestry governance (Cadman 2009). There are clear policy provisions about the structure and function of CFUGs (CFD/DoF 2009) and common to all CFUGs of the country. However, the decision making process in a CFUG may differ in practice. Therefore the decision making process of CF may affect carbon quantities in forests under the REDD+ project.

2.5. Economics of REDD+ in CFs

GHGs are considered as a commodity with CO_2 equivalent the unit used in carbon trading mechanisms (Hepburn 2007; Laurance 2008). The REDD+ project is focused on changing the existing behaviour of relevant actors to reduce deforestation and forest degradation and preventing future threats of deforestation and forest degradation (Lin *et al.* 2012). Through these activities, greater carbon quantities are added in forests compared to the historical trend for carbon stocks (Fry 2011); these quantities are monitored and verified in order to estimate carbon credits and additionality.

Poverty eradication is a millennium development goal (Sachs & McArthur 2005) and poverty reduction has been envisioned as one of the major co-benefits that REDD+ might bring (Vatn & Angelsen 2009). However, concerns about the relationship between communities' sacrificed benefits and REDD+ benefits need to be assessed. Since forest resources are important for the livelihood of local communities, the REDD+ mechanism should consider their needs and ensure that the outcomes are profitable for them. Poor communities are conserving forests with an expectation of livelihood support in Nepal (Subedi 2006); therefore, the contribution of the REDD+ mechanism to poverty reduction co-benefits is important, together with any biodiversity, water and recreation benefits in CFs. Moreover, there could be an expectation that REDD+ will bring additional benefits to local communities which will be higher than communities' associated foregone costs. However, there is no clarity in this regard. To assess the REDD+ project in CFs, Cost Benefit Analysis (CBA) could be done by establishing a business-as-usual case (the without REDD+ project situation) and assessing changes with a REDD+ project by disaggregating the individual activity value (Pearce *et al.* 2006).

The Master Plan for Forestry Sector (1988) and tenth five year plan 2002–2007 of Nepal (NPC/GON 2002) are focusing on an economic development agenda and the forestry sector is mentioned as a possible sector to consider. In addition to products based income from forests, the PES is also a possible option to incentivise the local poor for their forest management contributions (Subedi & Singh 2008; Pandey *et al.* 2011). Each CFUG can put in place different conservation efforts by following their economic development agenda (Adhikari & Nagata 2004; Maskey *et al.* 2006). Since the REDD+ mechanism needs to safeguard the needs and good practices of communities, analysing changes in costs and benefits for REDD+ projects is important. Therefore, all direct costs sacrificed due to changed forest management and use practices are equally important. However, the optional value of land in CFs does not need to be considered in the Nepalease context because CF lands are owned by the government and communities are not permitted to change the land use system (GON 1993). In the following sections, a review of possible forest product benefits and contributions of communities to REDD+ is presented.

2.5.1. Costs due to sacrificed benefits of communties for REDD+ mechanism

Though protecting forests by providing legally ensured ownership and supplying forests products for the subsistence household needs of local communities was a main aim of CF in its inception phases (Gilmour *et al.* 2004; Sunam 2011), it has expanded towards the economic development of local people from sustainable use of forest resources through to enterprise approaches (Subedi 2006; Adhikari *et al.* 2007). Local communities are extracting various products and generating income in CFs (Subedi 2006; Adhikari *et al.* 2007). However, communities may need to change such benefit practices to deliver REDD+ carbon benefits that can add costs of communities. The following are possible key benefits obtained in CFs which may be changed for REDD+ projects:

- Forest products benefits (Yadav *et al.* 2003; Adhikari & Nagata 2004; Cooke *et al.* 2008; Davidar *et al.* 2008;):
    - Extraction of timber: Timber is one of main building materials collected from forests. In a CF, the executive committee decides to give a certain amount of timber to its members for their own use. CFUGs can also sell the timber if they have excess quantity of the annual allowable timber harvest in a year. As an institution, a CFUG should maintain records of annual timber harvest from a forest (CFD/DoF 2002).

    - Extraction of fire wood: As noted, fire wood is a very important forest resource in rural areas. Rural communities extract wood and trees to fulfil household energy demand. Each CFUG has different firewood demand and they are extracting different quantities from forests (Agarwal 2001; Adhikari *et al.* 2007).

    - Extraction of fodder and grasses: CFUGs have different provisions for collecting fodder and grasses in CF to feed their livestock. Since each individual household has only a small agriculture landholding (the national average is <0.5 ha per household) (CBS 2011a), they may not able to supply enough fodder and grasses from their own land and therefore they depend on CF.

    - Extraction of litter: Litter is fallen leaf and twigs which is collected from the CFs and use as bedding material for livestock. Decomposed litter, after it is used as bedding material, is used as agricultural manure (Adhikari & Nagata 2004). As litter is dried and fallen leaves, most CFUGs allow this to be collected in forests.

    - Extraction of non-timber forest products (NTFPs): NTFPs are also a source of income for rural communities. People collect various parts such as leaves, fruits, roots and stems of NTFP plants from forests (Edwards 1996). Usually, NTFPs collected from CFs are sold and the annual sale of each CF is recorded because financial reporting is made compulsory by CF guidelines (CFD/DoF 2009).

  - Grazing livestock (Buffalo, Cow, Buffalo and Goat) in forests: Livestock is one of the important income generating options of rural communities particularly in agriculture based economies (Dhakal *et al.* 2005; Das & Shivakoti 2006). Seasonal grazing of livestock in the forest occurs in CFs (Dev *et al.* 2003) but if grazing pressure is heavy (more than the carrying capacity of the forests) it may degrade forests (Blackmore & Vitousek 2000). Most CFUGs are gradually reducing grazing intensity compared to earlier levels (Acharya 2002). This might be changed further for REDD+ which could increase the sacrificed benefits of communities.

- Social benefits: The REDD+ project may help to build greater social capital than CF particularly in terms of institution building, networking and linkage, and awareness raising (Kanel & Kandel 2004; Pokharel 2011; ANSAB/ICIMOD/FECOFUN 2013). As the REDD+ mechanism is new, it may be necessary to develop new institutional arrangements at various levels from local to international to facilitate the incentive mechanism, improve connections with various relevant institutions to explore opportunities and bring new knowledge which will be helpful to individuals and their society. However, social benefits may not provide direct economic incentives to poor people therefore it may not motivate poor communities to sacrifice existing forest product related benefits.

- Carbon benefits: Carbon trade is evolving under the global climate change policy process after the Kyoto protocol (Kyoto-Protocol 1997; Woerdman 2000). There is the possibility of generating additional income from carbon trade for CFUGs because local communities can generate additional carbon stock in their forests (Dev *et al.* 2003; Maraseni *et al.* 2005). Carbon credits generated in CFs may get premium prices in markets in future if global communities recognise that these forests have maintained co-benefits including biodiversity, the water cycle and the traditional practices of local communities in addition to carbon sequestration.

- Climate change adaptation: Forests provide food and fibre to surrounding poor communities (Wunder 2001; Sunderlin *et al.* 2005). If people cannot grow sufficient agricultural crops due to climatic conditions (e.g. prolonged drought, flooding) or other causes (e.g. war), they go and collect food supplements from forests (Falconer 1990). CFs can provide food supplements during times of food scarcity but to do so the diversity of species in forests must be maintained (Shrestha & Dhillion 2006). If there has been a reduction in the diversity of plants to stands dominated by only a few species with high biomass stock, a forest may not provide adequate food supplements to poor people and enable them to survive during adverse conditions.

2.5.2. Costs due to added efforts of communties in forest management

Communities are making efforts to conserve and improve forests in CFs through two means: 1) decision making processes (i.e. General Assembly (GA) and meetings), and 2) forest management (i.e. silviculture operation, plantation, fire control and guarding against illegal activities) (Acharya 2004; CFD/DoF 2009). The annual total value of these contributions can differ between CFs. Average annual changes in costs from before to after REDD+ project activities indicate total foregone or sacrificed benefits to communities. As CFUGs are operating following activities in CF practices (CFD/DoF 2009), they may have changed existing practices that can add to the sacrificed benefits due to REDD+:

- Executive committee meeting (number)
- Plantation
- Forest fire control
- Measuring & monitoring forest-C stocks
- Silviculture operation
- Harvesting of forest products (timber and NTFP)
- Guarding

2.6. Review of research methods related to CF studies

In order to understand the socio-economic aspects of CFUGs, forest management and forest product use practices, and factors associated with forest management, people-related data are required. In previous studies, social data are collected by random sampling methods in which issue-specific data is collected by using household surveys, focused group discussions and key informant survey tools (Ostrom 1990; Agrawal & Ostrom 2001; Varughese & Ostrom 2001; Adhikari *et al.* 2004; Maskey *et al.* 2006; Agarwal 2009). Household surveys through face to face interviews are considered the better option because the interviewer can explain questions if interviewees do not understand and bring the facts. This is effective in the case of Nepal where adult men usually go away from their village in search of paid work (Seddon *et al.* 1998) and the individuals who stay at home in rural areas are comparatively illiterate. Focus group discussion is another data collection tool used in social research where the perceptions of communities are collected from representative members of the different community groups (Pandit & Bevilacqua 2011). The key informant survey method is also used in social research (Marshall 1996) to gain deeper understanding of issues and to cross-check with other research approaches. Key individuals who work on issues or are associated with the issues are selected as informants and asked their opinions.

All these three methods are valid approaches when conducting social research related to the REDD+ in CFs. Estimation of cost and benefits for the REDD+, identification of key possible factors responsible for carbon increments in REDD+ CFs and exploring the perceptions of local people are possible by using these tools and methods. In many cases, mixed methods (i.e. questionnaire survey and/or FGD and/or key informant survey with checklist) are used to get complete data with cross-verification (Johnson & Turner 2003). Careful development of the data collection tools (questionnaire and check list) to ensure all possible variables are covered and can be analysed in the social research is important (Bernard 2000). Detailed data collection methods and analysis used in this study are discussed in the methodology chapter.

2.7. Monitoring methods of the REDD+ activities

Differences in carbon stock in forests with REDD+ project activities are estimated in order to understand the project performance (IPCC 2006). Remote sensing data such as SPOT satellite data and Landsat imagery can be useful to estimate historical rates of deforestation and estimate the carbon stock changes due to reduction in deforestation rates (Eckert *et al.* 2011; Hett *et al.* 2012). In order to estimate forest degradation, high resolution satellite imagery, ground-based inventory and well developed statistical models with relationship between the reflectance pattern of images and above ground biomass are required (Eckert *et al.* 2011; Sloan & Pelletier 2012). Although biomass analysis from remote sensing data including Landsat, ASTER and SPOT is often used, LiDAR has been increasingly employed in recent years (Gibbs *et al.* 2007; Avitabile *et al.* 2012). This is because LiDAR data gives the vertical structure of the forest on the basis of distance from the sensor to the ground (Næsset *et al.* 2011; van Leeuwen *et al.* 2011) and there are a strong correlation between LiDAR data and above ground biomass (Drake *et al.* 2003; Næsset *et al.* 2011).

Although monitoring of the sustainable management of forests is difficult, it can be done with pre-defined principles, criteria and indicators available at the global level such as those developed by the International Tropical Timber Organisation (ITTO), the Forest Stewardship Council (FSC) and the Montreal Process (McDonald & Lane 2004). These indicators include some aspects of the carbon cycle and ecosystem services, but are not directly relevant to the REDD+ concept. Existing indicators such as these can provide guidance to the development of criteria and indicators for REDD+ (Næsset *et al.* 2011;van Leeuwen *et al.* 2011; Sloan & Pelletier 2012).

Similar to the other REDD+ activities, monitoring of conservation and carbon enhancement can be done against a baseline identified from historical data and used to compare the carbon increment in forests under REDD+ activities. The baseline is adjusted to take in account the national circumstances of a country mainly by considering development adjustment factors. If a country need massive infrastructure, their deforestation rates could be higher. However, Nepal is already listed as a country with late transition state of deforestation and improving forests status (Hosonuma *et al.* 2012) there is likely to be increased carbon stock rather than a reduction and such possibilities are taken into account .

In CFs, deforestation activity is unlikely because local communities are not allowed to change forests into other land use practices. CFUGs are allocated a patch of forest to improve and are allowed to use a certain proportion of the increased amount of forest products (GoN 1993; CFD/DoF 2009). Detailed estimation methods used in this study are discussed in the methodology Chapter.

2.8. Carbon prices in the existing market place

Carbon offsetting is becoming a popular means of taking action to reduce GHG emissions and addressing global climate change. It neutralises a unit of CO_2e (carbon dioxide equivalent) emitted in one place by avoiding the release of a unit CO_2e elsewhere or sequestering a unit of CO_2e that would have otherwise remained in the atmosphere (Taiyab 2006). There are two market mechanisms, namely compliance market and voluntary market, for carbon offsetting and mitigating global climate change (Hamilton *et al.* 2008; Kollmuss *et al.* 2008; Peters-Stanley & Yin 2013).

Compliance markets are created and regulated by mandatory international, regional, and sub-national carbon reduction schemes such as the Clean Development Mechanism (CDM) regulated by the Kyoto Protocol and the European Union's Emissions Trading Scheme (EU-ETS). These systems provide options to countries (which have accepted limits for GHG emissions under UNFCCC) to meet their emission reduction targets. At present, EU-ETS does not accept credits from land use, land use change or forestry (LULUCF) projects, which are considered temporary in nature, but there are suggestions that such temporary credits may be included in the next phase of the scheme (Graichen 2005; Schlamadinger *et al.* 2005). By comparison, the CDM is a common mechanism which includes afforestation and reforestation projects; this mechanism follows a procedure to ensure the Certified Emissions Reduction (CER) by third party validation and verification (Hamilton *et al.* 2008; Kollmuss *et al.* 2008; Peters-Stanley & Yin 2013). Currently, market prices of CO_2e in CDM are reduced compared to 2008 (Table 2.2).

Voluntary markets are not regulated by mandatory schemes; however, they facilitate companies, government, organisations, organisers of international events and individuals to purchase carbon offsets for their carbon emissions on a voluntary basis. This mechanism provides opportunities for companies and private institutions to neutralise their emissions if this is of interest. The price for emission reductions in the voluntary market is largely driven by buyers' willingness to pay and sellers' willingness to accept payment (Taiyab 2006; Peters-Stanley & Yin 2013). The price of CO_2e on the voluntary market ranges according to projects and buyer interests (Table 2.2).

Table 2.2 Price of carbon dioxide equivalent (CO_2e) in three different carbon marketing mechanisms where LULUCF sector is included

Compliance market	Price at 2008 (US$/Mg$CO_2$e)	Price at 2012 (US$/Mg$CO_2$e)
California climate action	US$5 to 14 /Mg$CO_2$e depending upon location and guarantee (Capoor & Ambrosi 2009)	Auction price is set at US$10/Mg$CO_2$e. It offer auction four times a year at three prices levels: 40, 45 and 50. With 5% plus inflation each year (World-Bank 2013)
CDM	US$10-23 /Mg$CO_2$e (Capoor & Ambrosi 2009)	US$ 0.26 /MgCO_2e December (World-Bank 2013)
Voluntary market	US$1.20-46.90/Mg$CO_2$e; forest management US$7.7 /MgCO_2e (Hamilton *et al.* 2009)	US$5.9 /Mg$CO_2$e (Peters-Stanley & Yin 2013)

Prices are comparatively higher in voluntary markets than through the CDM. Carbon credits generated from forests do not reach the higher rates of energy projects because forestry projects have higher uncertainties compared to energy projects regarding emissions reductions (Chomitz 2000). The REDD+ is a new likely mechanism but yet to be developed a market mechanism. However, some pilot carbon projects have been priced: e.g. US$4–10/MgCO$_2$e in Uganda (Peskett *et al.* 2011); US$5/MgCO$_2$e in Cambodia (Sasaki *et al.* 2013); and in early 2013 REDD+ project received an offer in a range of US$7 and 8/MgCO$_2$e for forward REDD+ credits (World-Bank 2013). This shows the possibilities of the REDD+ mechanism on the market. In Nepal, the REDD+ project has distributed payment differently, with weighted payments of 60% based on social aspects and 40% on environmental aspects including 16% for carbon increment and 24% for biomass stock (Maraseni *et al.* 2014). This approach considers socio-economic safeguards while less emphasis is given to the added carbon.

2.9. Review of existing models for forest growth prediction

The quantity of carbon stock in a forest differs according to climatic, ecological and site specific factors (Houghton *et al.* 2001; Zhao & Zhou 2006). Forests sequester additional carbon with biomass growth (MacDicken 1997; IPCC 2006; Ordóñez *et al.* 2008).Therefore growth projections under undisturbed conditions and under community management are important when planning carbon stock enhancement projects in CFs. Projecting the growth of biomass carbon in different situations (undisturbed and community management) may need time series data. However, the use of the most relevant existing model is a better option for projecting the growth of forests if no time series data are available (Landsberg & Waring 1997). Broadly, the empirical forest yield model, ecological gap model, process model, and hybrid model are used to estimate yield in forestry (Monserud 2003).

Among these models, the empirical yield model predicts expected yield under a certain management regime over time from a direct statistical relationship. There are several empirical models developed in Nepal. These include models to predict: the total and merchantable volume and biomass of trees (Sharma & Pukkala 1990); early growth of *S. robusta* (Acharya & Acharya 2004); tree stem biomass and volume of *S. robusta* in central Nepal (Laamanen *et al.* 1995); diameter growth of *S. robusta* trees (Korhonen *et al.* 1992); fresh biomass and volume of trees in community managed forests (Tamrakar 2000); stand volume by age of *S. robusta* dominated forests stand (Rautiainen 1995); biomass estimation for 9 years *Pinus roxburghii* trees (Applegate *et al.* 1988a; 1988b); and biomass of 10 years old mix young stand of *Pinus roxburghii* and broadleaf species (Mohns *et al.* 1989). Yield models are simple, more efficient and provide better estimates than other forest growth models (Weiskittel *et al.* 2011). However, they require substantial site specific and species specific time-series data generated either by repeated inventories or chronosequences to estimate parameters (Monserud 2003). The ecological gap model is an individual tree based model designed to study tree population dynamics in forest patches. This model predicts dbh growth by age based on population dynamics (Risch *et al.* 2005) and requires information regarding gaps, recruitment, growth and mortality of individual trees in forest patches (Pabst *et al.* 2008). The gap model is used to analyse disturbances and effects on vegetation types, sizes and stocking rates (Mailly *et al.* 2000). The process model develops key processes and underlying causes of productivity including photosynthesis, respiration, nutrient cycles, climate effects and water stress to predict yield (Monserud 2003). For example, the 3-PG (Physiological Principle in Predicting Growth) model is one of the process based models adopted in growth prediction (Landsberg & Waring 1997). On the other hand, a hybrid model is a mixture of both empirical and process based yield models which merge the best features of both (Monserud 2003). The Triplex model is an example of a hybrid model (Peng *et al.* 2002).

Although both the 3-PG model and Triplex models are tested to predict forest yield, mostly the 3-PG model was used for single species plantation forests (Sands 2000; Almeida *et al.* 2004) and Triplex model was used for mixed vegetation (Zhang *et al.* 2008). Both these models need various parameters which may not be available for all forest types, particularly in developing countries like Nepal. Required parameters for this model include climatic data (average precipitation, temperature and relative humidity), photosynthetically active solar radiation (atmospheric absorption factor, solar radiation fraction), gross primary production of a forest (maximum canopy conductance, stomata conductance, canopy boundary layer conductance, coefficient for conductance to vapour pressure deficit, minimum temperature for growth of the forests, maximum temperature for growth of the forests, optimum temperature for growth of the forests, nitrogen factor for tree growth), soil carbon and nitrogen (lignin–nitrogen ratio, lignin for leaf, fine root, coarse root, branch, and wood) and soil and water data (depth of soil layer, relative root density for layers, fraction of water flow to stream, fraction of water flow to deep storage, fraction of deep storage water to stream, maximum soil water) (Peng *et al.* 2002). These parameters are different for each vegetation type and may need long term research to identify.

Similarly, the Full Carbon Accounting Model (FullCAM) developed for estimating Australia’s national greenhouse gas emissions and removals due to land-use, land-use change and forestry provides a comprehensive approach (Paul & Polglase 2004). Although this is national model, it can provide a framework to adopt in other countries. This also uses parameters of the 3-PG model.

As mentioned earlier, both field inventory and remote sensing data is being used in above ground biomass prediction (Avitabile *et al.* 2012). Use of remote sensing data (satellite imagery and LiDAR data) in REDD+ carbon stock monitoring is a better option (Hett *et al.* 2012; Romijn *et al.* 2012). LiDAR data give the vertical structure of biomass in forests and are therefore better for estimating forest degradation (Gibbs *et al.* 2007). However, there are possibilities of missing small patch of disturbances in land cover data (Avitabile *et al.* 2012). Therefore, high resolution images and proper interpretation of images with field verification is important for accuracy. However, developing countries need to build their capacity to use remote sensing based data in forest monitoring (Romijn *et al.* 2012). In this context, empirical models could be better for predicting biomass in REDD+ CFs for Nepal.

A number of methods, including destructive, non-destructive or the use of existing allometric equations, are used to estimate biomass carbon. In destructive methods, all trees are harvested and weighted. Although, this method is relatively accurate, it is time and resource consuming (Nordh & Verwijst 2004; Tyagp *et al.* 2009). In the case of non-destructive methods, parts of trees are measured and a regression between vegetation cover and biomass performed which needs detailed measurement and analysis (Flombaum & Sala 2007). The use of existing species-specific allometric equations is quicker. However, in order to develop biomass tables or allometric equations, initial data must be collected using the destructive method (Rautiainen 1995; Chave *et al.* 2005; Chapagain *et al.* 2013). Once these equations have been developed, they can be applied more broadly across large areas with similar climatic, topographic and management practices (Alamgir & Al-Amin 2008; Henry *et al.* 2010).

Repeated measurements and data collection are required to develop growth models (Vanclay & Skovsgaard 1997). Therefore, the establishment of permanent experimental plots is needed in order to establish carbon increments in forests (MacDicken 1997; Subedi *et al.* 2010). In short term studies, an existing model or yield table are the best option for estimating biomass carbon with one variable. A model developed by Rautiainen (1995) for *S. robusta* forests was found to be applicable in predicting biomass carbon growth for undisturbed forests. The data tested for this model was collected from undisturbed *S. robusta* forests with 20% of other species of Terai and Bhabar area in Nepal. This model has been used in other related researches (Gautam & Devoe 2006; Sapkota & Meilby 2009).

2.10. Theoretical frameworks related to REDD+ in CF study

Study related to CF and the REDD+ mechanism are linked with environmental, social and economic theories. More relevant theories of this study are forest governance particularly common pool resource management (Hardin 1968; Ostrom & Gardner 1993), forest yield (Smith *et al.* 1997; Khanna 2004), self- determination in human motivation (Deci & Ryan 2000), political economic theory or economic tranformation theory (Breisinger & Diao 2008) and Pareto improvement in welfare economic (Hochman & Rodgers 1969; Chou & Talmain 1996). Linkage of these theories in REDD+ is shown is figure 2.3.

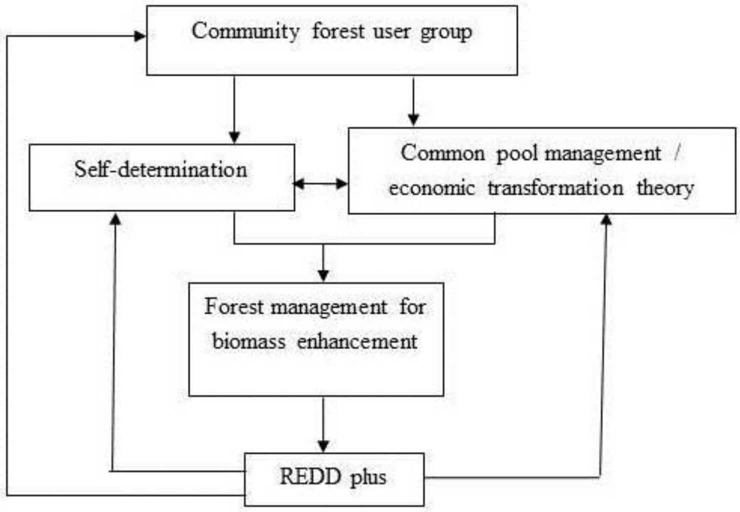


Figure 2.3 Theoretical aspects for REDD+ in community forestry

In common pool resource management theories, the theory of "tragedy of the commons" says that the collective actions of individuals with common ownership inevitably lead to degradation of the common resources (Hardin 1968). This concept evolved during the early 1970s from studies investigating whether the degradation of common pool resources happens due to overuse practices of the communities; these studies found that external interventions were needed to control it (Ostrom 1990; Ostrom *et al.* 1994; Gibson *et al.* 2000). In opposition to this concept, another theory emerged that the common resources can be conserved and individuals work better if there is a mechanism of sharing rights, responsibilities and benefits of the common pool resources (Schlager & Ostrom 1992; Edwards & Steins 1999). For this to occur, proper communication and good governance mechanisms are important to facilitate the sustainable management of the common resources (Ostrom 1990; Agrawal & Ostrom 2001). However, there are still gaps in the literature about the reactions of communities and outcomes if some external motivating factors (such as monetary incentives from REDD+) come into the existing common pool management practices. If local communities start to invest additional efforts as a result of incentive oriented motivations, this cost and the possible benefits from these efforts may need to be assessed. If there are higher added costs than possible benefits of REDD+, understanding of the response of common pool resource managers toward their performance is important.

In the case of CFUGs, communities are operating in a complex social structure with a heterogeneous economy and forest product needs, where the collective efforts of all community members are expected. REDD+ interventions can motivate user communities to change existing activities (Caplow *et al.* 2011). They change those activities either through intrinsic motivation of their own or extrinsic motivation from external incentives (Deci *et al.* 1999; Deci & Ryan 2000; Gagné & Deci 2005). Extrinsic motivation impacts the autonomy of individuals. Therefore the self-determination theory (Robert 1991; Deci & Ryan 2000; Gagné & Deci 2005) assumes that people act from a combination of intrinsic and extrinsic motivations. Most of the present studies relate to motivation in regard to the human resources aspect of the organisation, but this may also be applicable in the CFUGs and REDD+ outputs. Incentives of REDD+ may be an extrinsic motivation factor for CFUGs and they can be motivated with the expectation of appropriate incentives. If communities are getting fewer incentives than foregone sacrificed benefits, their efforts may not be continued in the long term. In this situation, if their efforts are not driven by intrinsic motivation, the outcome will not be sustainable.

Within the REDD+ context, political economic theory, mainly transformation theory, is also relevant. As REDD+ is emerging as a new paradigm for forest management, it that may require new institutions, the involvement of new stakeholders, new knowledge about forest management and new incentive mechanisms, the complete transformation of existing mechanisms or the generation of new systems will be required for the effective implementation of REDD+ (Angelsen *et al.* 2012). This transformation may change existing power relationships between government authorities and Community Forest User Groups (CFUGs). Carbon benefits with financial flows from overseas may come through central government and, as such may run the risk of centralising power from CFUGs. This will be problematic due to current land tenure system of community forest management – a system where land tenure is with government (GoN 1993) and carbon payments may be linked with tenure rights (Corbera *et al.* 2011) therefore communities may not able to access them directly. Similarly, the REDD+ mechanism may add to the institutional complexity associated with distributing financial benefits at a community level; and this can add further problems in heterogeneous communities where inequality in benefit sharing already exists in a CFUG (Malla *et al.* 2003; McDermott & Schreckenberg 2009). This may affect existing community forestry systems and drive further social instability.

Current annual increment (CAI) measures yield in terms of of tree volume. CAI is slower at juvenile age, higher at younger stages of the forest stands and gradually decreases to zero as a stand ages (Birch 1999; Husch *et al.* 2003). In forests, growth rates vary with species compositions, climatic factors, site factors, average stand age, disturbances and forest product extraction. In CF, community activities may have obstructed the natural growth of the forests. However, if a forest is managed conservatively, forest stands will reach an equilibrium stage after a certain time with CAI zero. The yield also depends on the silviculture operation and harvesting intensity. An appropriate silvicultural operation reduces competitors of the trees and increases the growth of remaining trees in the forest stands (Thornley & Cannell 2000; Poorter 2001; Ishii *et al.* 2008; Harmon *et al.* 2009).

2.11. Conclusions

The review of the existing literature indicates that the REDD+ incentive based mechanism in developing countries is likely to come into future global GHG reduction agreements. However, there are gaps in scientific knowledge, particularly about REDD+ in respect to CFs. In order to design a sustainable REDD+ mechanism in CFs, the following gaps identified in the document review need to be addressed in future research:

- <u>Potential carbon stock enhancement in CF:</u> There are limited studies on existing carbon stocks in CFs. Knowledge of the current carbon stock of CFs is important when designing an appropriate benefit distribution mechanism for REDD+. Similarly, the technical potential carbon enhancement in CFs is important to enable prediction of future scenarios of REDD+; this is not clear at present. If a forest is left without disturbances, the natural growth of forest stands can achieve an equilibrium stage with high levels of carbon stock; however, many human activities in CFs can prevent a forest from attaining this. Gaps between the technical potential carbon stock in forests without human disturbances and carbon stock with community interventions in CFs are not well understood.

- <u>Factors affecting carbon enhancement in CF:</u> The existing literature focuses mainly on the global perspectives of the REDD+ mechanism. Those studies cover factors affecting deforestation and forest degradation in national contexts. However, there is limited knowledge about the local potential factors affecting carbon stocks in CFs as most of the present studies have limited coverage of this regime.

- <u>There is a gap in project level research on REDD+ demonstration activities</u>: There are limited studies available on REDD+ demonstration projects. The lessons from these REDD+ demonstration project activities and outcomes are important in developing the REDD+ policy and institutional set up.

- Trade-off between sacrificed community benefits and REDD+ benefits is unclear: As overall aim of the REDD+ mechanism is to provide incentives for forest improvement performance in developing countries. At present, there is no clarity in the literature about trade-offs between community foregone sacrificed benefits and carbon benefits, particularly in CFs of differing dominant vegetation types. Knowledge about the benefits to local communities sacrificed to enhance unit carbon credit in CFs is important when designing an appropriate REDD+ incentive mechanism, but is currently lacking.

In a nutshell, the identification of factors associated with a higher rate of carbon sequestration in CFs and lower trade-offs in terms of community benefits is important for the design of REDD+ in CF. Analysis of the trade-off between forgone sacrificed benefits of communities and carbon benefits would help in identifying whether REDD+ is beneficial for CFs or not and which types of species dominated CFs are more beneficial. This field based study expected to contribute on these gaps in knowledge to help improve the ongoing approaches and practices of REDD+ projects to achieve both community and carbon sequestration benefits. To address this research issue and specified objectives, the next chapter will detail the methodology used for this study.

CHAPTER THREE

RESEARCH DESIGN AND METHODS

3.1. Introduction

The previous chapter gives a review of existing knowledge about climate change, the role of forests in mitigating climate change and REDD+ in CFs, relevant theories and knowledge gaps. This chapter presents the methodology used to address the research problems identified in Chapter One. The Overarching goal of the study was to answer four major questions: 1) What are the carbon stock dynamics in CFs with REDD+ program; 2) What is the technical potential and actual growth of carbon stock in CFs; 3) What are the possible factors affecting carbon stock changes in CFs; and 4) What are the trade-offs between carbon stock and community foregone sacrificed benefits in REDD+ CFs.

Both biophysical and socio-economic data were used in this study. Biophysical data includes carbon pools, canopy structure, vegetation measurements (tree, sapling and regenerations), average age of the dominant trees in plots, altitudinal location of the forests above sea level, proximity of the forests from settlement and road head, and incidences of biomass reducing factors in forests. Similarly, socio-economic data includes demographic information of CFUGs (population, caste group), average household level agriculture land holding, average household level livestock and change after the REDD+ project, average household level forest products use and changes in quantity after the REDD+, average number of households using alternative energy, grazing practices (livestock unit in forests), cost and benefits of communities due to changed forest management practices and changed forest product use practices for the REDD+ in CFs. The carbon pool data were collected from February to May of each year of 2010, 2011, 2012 and 2013, and the data related to socio-economic aspects of communities was collected from November 2011 to March 2012. During carbon pool measurement, observation and recording of evidence of biomass reducing factors namely forest fire, livestock grazing, fodder collection, firewood collection and timber harvesting was done for all plots to analyse changes in such incidences after REDD+ project.

This chapter has been organized into eight sections. The next section gives a description of the study areas covering demographic information, location map, precipitation and temperature, vegetation types, forest management practices and REDD+ project activities in CFs. The third section gives methods used to estimate stocking rates of vegetation, carbon stock and change in carbon stock in CFs. The fourth section explains the methods used to analyse the potential growth of carbon stock in the REDD+ CFs. The fifth section includes methods used for analysing demographic information, forest management practices, changed behaviour and cost and benefits of CFUGs for REDD+. The sixth section describes methods used to analyse factors affecting carbon stock and carbon stock changes in CFs. The seventh section gives methods about analysing trade-offs between carbon benefits and community benefits. The final section concludes the chapter.

3.2. Description of the study areas

The study area covers 105 CFUGs in three watersheds, one watershed in each of three districts namely, Kayerkhola watershed in Chitwan, Ludikhola watershed in Gorkha and Charnawati watershed in Dolakha (Figure 3.1). These areas represent diverse social (people with ethnic differences) and ecological (altitudes and vegetation differences) aspects. The area is the only REDD+ project that demonstrates REDD+ pilot project activities in CF in Nepal. The demonstration REDD+ pilot project was implemented for four years (2009–2013) jointly by the International Centre for Integrated Mountain Development (ICIMOD), Asia Network for Sustainable Agriculture and Bioresources (ANSAB) and Federation of Community Forest User Group (FECOFUN) under the financial assistance of the Norwegian Agency for Development Cooperation (NORAD). Unique characteristics and other details about the study areas are discussed in this section.

3.2.1. Demographic information of the study area

Among three watersheds, the Kayerkhola watershed represents the tropical lower altitudes terai, where 16 CFUGs are managing 2,381.8 hectares of forest area. In these 16 groups, diverse caste groups (Chepang, Tamang, Dalit, Newar, Gurung, Brahmin and Chhetri) are involved in forest management. Ludikhola watershed, which represents both the tropical and sub-tropical physiographic region, covers 31 CFUGs and their 1,887.7 hectares of forest area. Magar, Gurung, Tamang, Dalit, Brahmin and Chhetri caste groups are major residents in the Ludikhola watershed. Charnawati watershed represents subtropical and lower temperate physiography and includes 58 CFUGs representing Chhetri, Brahmin, Newar, Tamang, Thami and Dalit communities. These CFUGs are managing 5,996.1 hectares of forest area. Among caste groups of the study areas, Dalits, Chepang, Thami, and Tamang are more forest-dependent and they are also listed as socially underprivileged groups in the country (CBS 2011b). Comparatively, Charnawati watershed is larger in term of populations and forests areas and also in per capita forest distribution, while Kayerkhola has the smallest population and the Ludikhola watershed the smallest area of forest (both total and per capita area) (Table 3.1).

Table 3.1 Demographic information and size of forests in the study areas

S.N.	Sites	CFUGs (No.)	Households (No.)	Population (No.)	Forests area (ha)	Per capita forest (ha)
1	Kayerkhola	16	3650	22090	2381.8	0.108
2	Ludikhola	31	4000	23197	1887.7	0.081
3	Charnawati	58	7730	48504	5996.1	0.124
	Total	**105**	**15380**	**93791**	**10265.6**	**0.109**

Note: CFUG= Community forest user group; No. = Number (Source: Operation plan and Constitution of CFs)

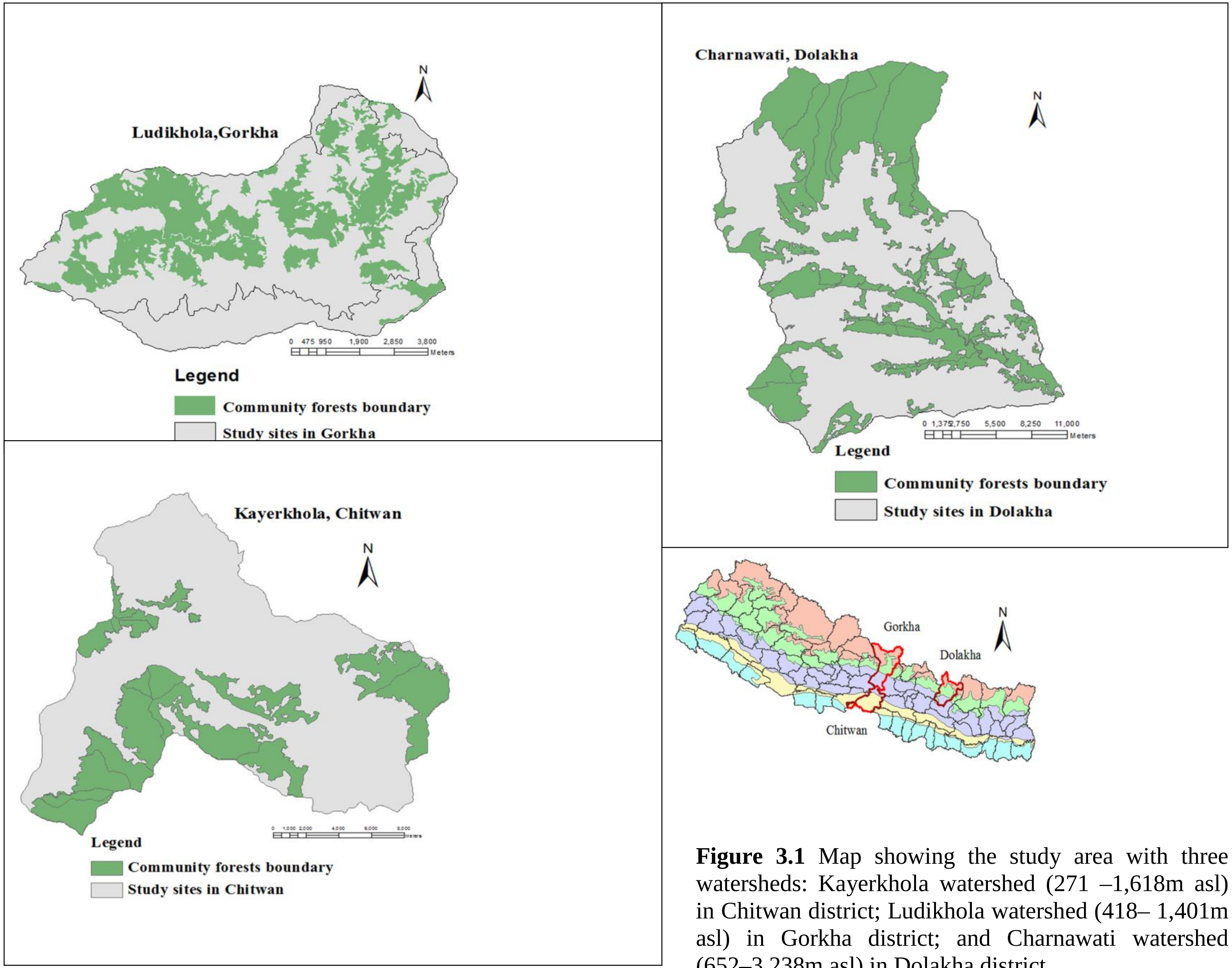


Figure 3.1 Map showing the study area with three watersheds: Kayerkhola watershed (271 –1,618m asl) in Chitwan district; Ludikhola watershed (418– 1,401m asl) in Gorkha district; and Charnawati watershed (652–3,238m asl) in Dolakha district.

3.2.2. Precipitation and temperature of the study area

Precipitation and temperature are key climatic factors affecting the growth of vegetation. This study area represents various forests with different temperature ranges and rainfall. Temperatures in the study area range from a maximum of 24.3–36.6^0 C to a minimum of -1.2–7.6^0 C. The average temperature of the Kayerkhola watershed in Chitwan is comparative warmer followed by Ludikhola, Gorkha and colder in Charnawati, Dolakha. Average annual rainfall is more than 1700 mm in all study areas (Table 3.2). The study areas receive precipitation in all but 1-2 months (December-January) of the year are dry (DHM 2013).

Table 3.2 Average meteorological information of closely located stations from three watersheds in 1976-2005

S.N.	District	Ave annual Temperature range (^{o}C)	Meteorological station	Ave annual Rainfall (mm)	Meteorolog ical station
1	Chitwan	Min 7.6; Max 36.6	Rampur	2009.6	Rampur
2	Gorkha	Min 5.4; Max 28.5	Syangja	1736.7	Gorkha
3	Dolakha	Min-1.2; Max 24.3	Jiri	2104.4	Charikot

Note: Min denotes average of the minimum temperature and Max means average of the Maximum temperature; *Source: Marahatta et al. (2009)*

3.2.3. Vegetation types of the study areas

The study areas cover a diverse ecology due to different physio-climatic characteristics. Dominant forest types ranges from *Shorea robusta* forests at lower altitudes through *Schima-Castanopsis* to *Rhododendron–Quercus* in higher altitude areas. Even though *S. robusta* mixed tropical and sub- tropical deciduous are major forest types in Chitwan and Gorkha, associated species are different: *Lagerestroemia parviflora*, *Mallatus phillipinensi* and *Terminelia tomentosa* are dominant associates in Chitwan whereas *Schima wallichii* and *Castanopsis indica* are the most common associates in Gorkha. While few *S. robusta* and *Schima-Castanopsis* forests are found in lower altitudes in Dolakha, the major vegetation types are *Schima-Castanopsis* and *Rhododendron* forests, extending high up to *Quercus* forest, representing the dominant lower temperate forests. Dolakha site has also some plantation forests with *Pine* species.

3.2.4. Forest management practice in the areas

Though the Forest Act 1993 and 1995 legislation mention government managed forests, private forests, religious forests, protected forests, leasehold forests and CF as major forest management systems of Nepal, the Master Plan for Forestry Sector gave priority to CF (MFSC 1988). CF is now considered a successful model for conserving forests, raising the awareness of local people, decentralising forest governance practices and proving socio-economic benefits at the local level (Acharya 2002; Adhikari *et al.* 2007; Pagdee *et al.* 2006). CF is expanding in Asia, Africa and other developing countries (Brown *et al.* 2002; Nurse & Malla 2006; FAO 2011) and the learnings from CFs are important for future policy processes intended to enable the REDD+ mechanism (Bluffstone *et al.* 2013).

CFs in the study areas have been started at different times with different enabling efforts. Dolakha and Gorkha districts are located to the hilly region of Nepal where CFs was started at earlier stages than in the terai low altitude areas of Chitwan (CFD/DoF 2013). Joint efforts of government institutions and other supporting institutions in the areas were important for this. Nepal Swiss Community Forestry Project (NSCFP) (a bilateral project of Swiss government and Nepal government) and Asia Network for Sustainable Agriculture and Bioresources (ANSAB) (a non-governmental organisation) were working to develop and promote CFs in Dolakha. They were supporting district forest offices and local communities to form CFUGs, organize communities, develop forest management plans and constitutions, develop and operate sustainable forest based enterprises and conduct plantation and silviculture activities. In Chitwan, the Danish International Development Agency (DANIDA) funded bilateral project the Natural Resource Management Sector Assistance Programme (NARMSAP) was working for CFs. Similarly, Care Nepal (a non-governmental organisation) and NARMSAP were working to advance CFs in the Gorkha district (DoF/MFSC 2005). Additionally, ANSAB together with Federation of Community Forestry Users Nepal (FECOFUN) initiated Forest Stewardship Council (FSC) certification in 2003 and brought a total of 11 CFUGs into the forest management certification pools in Dolakha (Biggs & Messerschmidt 2005).

3.2.5. REDD+ project activities in the study areas

During the project period (2009–2013), various activities including carbon monitoring, capacity building and institution building, interventions for reducing biomass extraction from the forests, promotion of alternative energy, plantation and improvement activities of forests were carried out. More specifically, the project implemented the following activities in CFs in the study areas:

a. Carbon stock monitoring in CFs: Measurement of carbon pools was carried out from February–May in 2010, 2011, 2012 and 2013.

b. Capacity building and institution development: The project organised training and interaction programmes at local and national level involving local communities, government and non-government organisation representatives who were working in forestry sectors. For raising awareness of the participants on various contemporary issues of REDD+, training and interaction events were designed covering subject matters related to the climate change mitigation role of forests, carbon monitoring mechanism and ongoing discussions and the possible mechanism of the REDD+. The project facilitated the formation of a loose watershed level REDD+ network by organising all CFUGs of that particular watershed and enhancing their participatory decision making processes in designing and implementing all REDD+ activities. The project also helped to revise the constitution and forest management plans of CFUGs incorporating those activities (ANSAB/ICIMOD/FECOFUN 2013).

c. Interventions for reducing biomass extraction: The project encouraged local communities to reduce the extraction of biomass, mainly the quantity of timber, firewood, grasses and fodder harvested from the forests, to better conserve and enhance carbon stocks in the CFs. The project distributed improved cooking stove (ICS) to the communities and provided subsidies to install and use biogas energy. The project also facilitated the building of biogas plants and ICS by establishing linkages to the government subsidy programme (ANSAB/ICIMOD/FECOFUN 2013).

d. Improvement of the forests status: The project assisted communities in the design and implementation of forest fire control, and the reduction of grazing and illegal harvesting activities. The project organized practical training for local communities about silviculture operations to enhance biomass stock in forests. It provided seedlings and technical guidance to carry out plantation activities (ANSAB/ICIMOD/FECOFUN 2013).

3.3. Method used to estimate stocking rate of vegetations, carbon stock and carbon stock changes in CFs

3.3.1. Inventory of vegetation and carbon pool

In order to estimate carbon stock in CFs for the reference year (2010) and changes in carbon stock after the REDD+ project activities in the following years (2011, 2012 and 2013), forest inventory data were obtained by collaborating with the project implementing institutions. Before measurement commenced, hands-on training and coaching was arranged for crew members to ensure their capability in generating accurate and consistent data in the field every year. The following steps were taken for carbon pool measurement:

a. Stratification of the forests

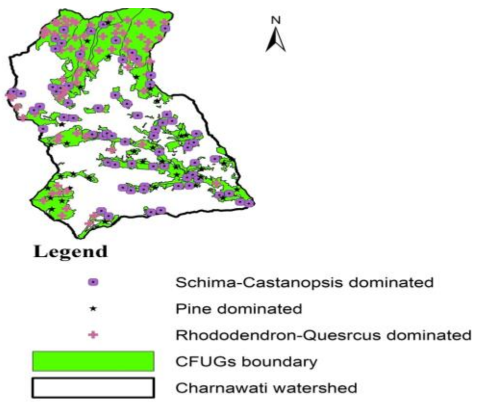
Stratification of the forests increases the precision of the inventory data (McRoberts *et al.* 2002); therefore, a stratified random sampling design was used in the study. Percentage of canopy cover and dominant vegetation types were taken as criteria for stratification. All forests of the study area were divided into two strata by canopy cover i.e. dense (i.e ≥70% canopy cover) and sparse (i.e <70% canopy cover). Satellite images (Geoeye) taken in November 2009 were analysed using GIS software IRDAS IMAGINE to identify forest areas with dense and sparse canopy cover types. Out of the total 10,265.8 ha of forests, areas of dense and sparse forests were estimated (7,436.8 ha and 2,829 ha, respectively).

b. Distribution and lay out of the sample plots

After stratification, a total of 490 composite plots including 95 plots in sparse canopy and 395 in dense canopy forests were proportionally established for annual carbon pool inventory. These sample plots covered >0.08% of forest areas of each stratum which is within the range of sampling intensity (0.05–7.8%) used in other forest inventory related studies (Brown & Lugo 1992; Magnussen & Boudewyn 1998; Bongers *et al.* 1999; Specht & West 2003).

These sample plots were distributed randomly in CFs covering all five dominant vegetation types; namely *S. robusta*, Mixed broadleaf, *Schima-Castanopsis*, *Pine*, and *Rhododendron-Quercus*. Hawth's analysis tool, developed by Beyer (2004) for ArcGIS to create random points in ecological and landscape level researches (Lanier *et al.* 2007; Haines *et al.* 2012), was used to distribute sample plots on the map (Figure 3.2).

A. Charnawati Watershed



B. Kayerkhola Watershed

C. Ludikhola Watershed

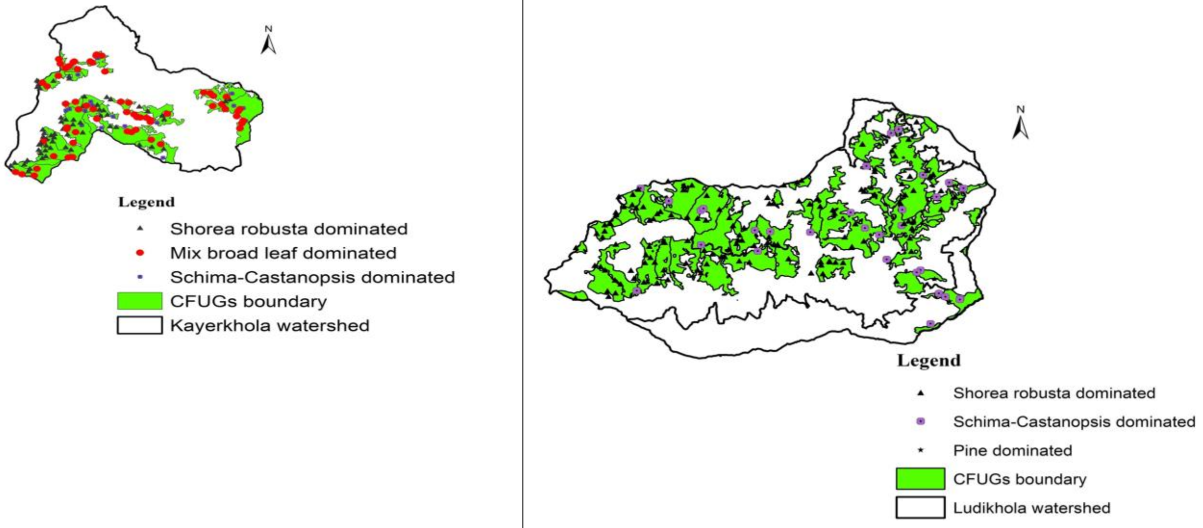


Figure 3.2 Distribution of sample plots in *S. robusta*, mixed broadleaf, *Schima Castanopsis* , *Pine* and *Rhododendron-Quercus* dominated forests in Charnawati watershed Dolakha (A), Kayerkhola watershed Chitwan (B) and Ludikhola Watershed Gorkha (C) of the study areas

Coordinates of the centre points of plots generated by Hawth's tool were loaded into a GPS and located in the field. After locating the points, circular composite plots were established on the ground for carbon pool measurement. A circular plot was used because it is easier to establish, especially in repeated measurements and commonly use in forest inventory (Jalonen *et al.* 1998). Moreover, the circular plot reduces errors with smaller perimeter than a rectangular plot of the same area (Goldsmith & Harrison 1976). With a smaller perimeter, a circular plot could have fewer trees and other measure of biomass within the plot boundaries (i.e. partially inside and partially outside the plots) that make easier for the crew to decide which materials to include in the plot and thereby increase the precision of estimates of biomass carbon.

Composite plots with different radius subplots were established for measuring different carbon pools in the forests at the GPS located points (Figure 3.3). From the central point, sub-plots with radii of 0.56 m, 1m, 5.64 m and 8.92 m were established to measure different carbon pools. Details about carbon pools and measurement techniques are discussed in later sections.

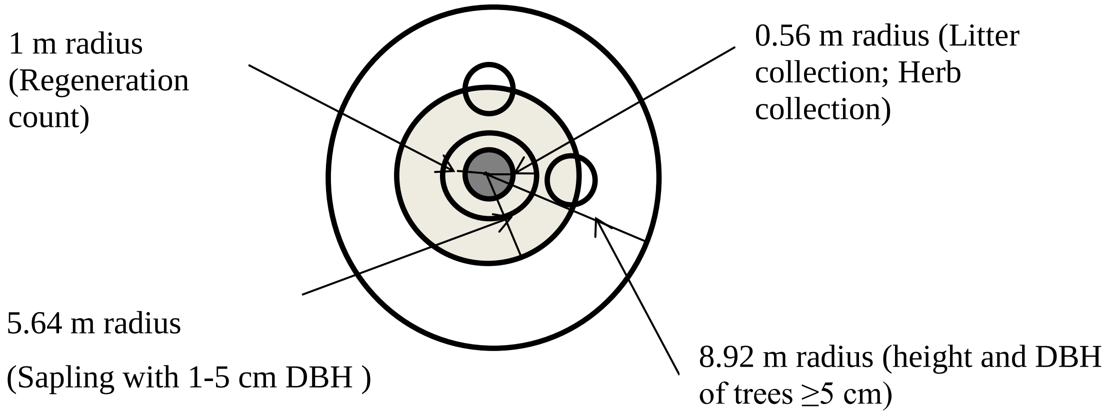


Figure 3. 3 Model of a composite sample plot used to measure carbon pools during forest inventory

Since, the study areas were not perfectly flat, slope distance was converted into horizontal distance which is the usual practice in forest inventory (Waddell 2002). This is because if the length was not converted it would represent a smaller area than in reality in two dimensions. Conversion was made by using the trigonometric relationship of horizontal distance, slope angle and slope distance (Horizontal distance=cosine slope angle*slope distance).

c. Information of plot

After locating and establishing the plots, dominant vegetation, altitude (above sea level) of the plots, incidence of biomass reducing events, average age of the dominant trees, and permanent reference marks of the plots were recorded at the beginning of the measurement using a pre-prepared form (Appendix E). Key biomass reducing events, namely forest fire, grazing and forest product (timber, fuel wood and fodder) harvesting in the plots for that particular year, were recorded. Before recording, it was first confirmed, with the local people who were present during the forest inventory in the plot, whether the incidence had happened in that particular year or not. Similarly, the average age of the dominant trees of the plot was asked of local people and forest technicians because they know starting time of protection activities and growth patterns, and can estimate present age (Griffith & Ram 1943; Rautiainen 1995). Quantitative techniques such as root system analysis or ring count were not applied because due to practical difficulties; such techniques require a lot of effort (Rautiainen 1995) and were not possible for this study.

d. Forest carbon pool and its measurement

According to IPCC Good Practice Gudelines (2006), above ground biomass, below ground biomass, litter and debris, and SOC are the key carbon pools found in forests. However, the guidelines provide flexibility to enable countries to decide which carbon pools to include or exclude in their national GHG accounting process based on shares in total emissions (IPCC 2006). Therefore, tree (above ground and below ground), sapling (above ground and below ground), herb (all living plants except trees, sapling and regenerations), litter (dry fallen leaves and twigs) were considered as carbon pools and measured for four consecutive years (2010, 2011, 2012 and 2013) in this study.

Inventory in the plots was scheduled for the same week (almost the same days of the month) of each year to avoid potential effects on the quantity of biomass in the plots due to different growth seasons of trees and herbs (Wright & Cornejo 1990; Moser & Hoveland 1996; Vaganov *et al.* 1999; Brienen & Zuidema 2005) and litter fall (Wright & Cornejo 1990). Smaller plots were used for both herbs and litter than for the other pools. This is because herbs and litter are smaller and need a rigorous process to be followed for destructive sampling. There are practices to establish smaller plots for inventory of small size plants (CFD/DoF 2002). A brief description of measurement techniques used in this study follows:

Tree measurement: A plant with ≥5 cm DBH is considered a tree. Trees sequester atmospheric CO_2 and store higher amounts of carbon compared to other biomass pools (Turner *et al.* 1995; Finér *et al.* 2003). During the field inventory, the names of tree species were recorded, and the height and DBH of trees were measured in the sample plots with radius 8.92 m. Diameter tape was used to measure the DBH of each tree at 1.3 m from ground because this is common in forest inventory practices (CFD/DoF 2002; Husch *et al.* 2003). Clinometer and compass were used to measure the angle and linear tape was used to measure distance from the bottom of a tree to the standing point of the crew member from which angle was measured to estimate tree height.

Sapling measurement: A woody plant with DBH 1 to 5 cm was considered a sapling. The names and DBH of saplings within plots of radius 5.64 m were recorded.

Herb measurement: Herbs were uprooted from 0.56 m diameter plots and fresh weight taken in the field. Of the total fresh weight of these thoroughly mixed herbs on each plot, a sample portion of 100 g was taken and sent to the National Agriculture Research Coulcil (NARC) laboratory of Nepal for dry weight estimation in the first year. Since destructive sampling was carried out in plots, the locations of the 0.56 m radius plots were shifted 5.64 m from north in second year, and the same distance in clockwise direction in following years i.e. perfect east in third year and perfect south in fourth year. Herbs were uprooted and only fresh weights were taken in the second, third and fouth years.

Litters measurement: Litter biomass (fallen leaves, small twigs) was measured in the same plots (with radious 0.56 m) in which the herbs were measured. Similar to herbs, all the litter was collected from the plot and the fresh weight taken. From the collected litter, a well mixed sample of 100 g weight was sent to the NARC laboratory for biomass estimation by the oven dry method. Only the fresh weight of litter in the plots was taken in the second, third and fouth years.

e. Excluded pools in measurement

Soil organic carbon (SOC): SOC is an important part of the forest carbon pool (IPCC 2006); however, this study excluded this pool. This is because SOC does not change over short periods of time under the same land use practices (Fearnside & Barbosa 1998; Houghton *et al.* 2000; Guo & Gifford 2002). Moreover, there is limited chance of humus accumulation in forests managed by communities where all fallen leaves and litter are used for cattle bedding materials and coarse woody debris are used for fuel-wood (Metz 1994; CFD/DoF 2009; Maskey *et al.* 2006) with no biomass left on the ground to decay. Therefore, the study assumed that there would not be much variation in SOC within the short timeframe, and that it remained almost constant during the study period compared to forests that have no collection.

Harvested wood products: Most of the harvested wood goes for fuel wood (even if it is timber) after a certain time; therefore, this study has excluded harvested wood from the measurements. Communities are allowed to harvest timber trees if they need to build or renovate houses (Adhikari *et al.* 2007) and old decaying wood has to be replaced. Most of the communities replace old timber with fresh during renovation and the old timber goes for firewood. Therefore, the study assumed that the quantity of harvested wood used remained almost constant in community households during the study period.

Regeneration: Number of recruits (plants with less than 1 cm diameter) was counted within 1 m radius plots in the field. The study excluded this in the biomass estimations because plants of this size contribute only a very small amount of biomass compared to other pools and destructive sampling to estimate regeneration biomass was not conducted.

3.3.2. Analysis of vegetation and carbon pool

a. Stocking rates of different size trees in forests

Physical and temporal distribution of trees in forests were analysed by canopy differences in each forest type. Particularly, stocking rates (i.e. numbers of regenerations, saplings and trees per hectare) available in CFs were analysed. This analysis was expected to generate knowledge about the distribution of different sized trees in forests to design a plan for maintaining normal forests i.e. larger stocking rates of smaller sized trees and gradual reduction towards larger sizes in the forest stands (Smith *et al.* 1997; Montagnini & Ashton 2010). Average stocking rates of each vegetation category in plots for the reference year 2010 and changes between 2010 and 2013 (after the REDD+ project activities) were estimated and compared.

b. Biomass carbon in forests

Biomass carbon in forests for a particular year was estimated in four steps: first of all the biomass of each pool in a plot was estimated; secondly, total biomass in each plot was derived by adding all individual biomass pools; similarly, total biomass was converted to carbon using the carbon fraction value (0.47); and the biomass carbon estimated for each forest type and individual CFs. Detailed analysis methods used in the study were as follows:

Estimation of above ground tree biomass (AGTB)

Though destructive sampling is reliable if samples adequately represent the stand, it is impractical, time consuming and expensive due to its destructive nature and the rigorous process involved (Verwijst & Telenius 1999; Tyagp *et al.* 2009). Therefore, this study used existing allometric equations (previously developed from destructive sapling from similar forests) combined with forest inventories, which is the method most commonly used to assess forest biomass (Chave *et al.* 2005; Alamgir & Al-Amin 2008; Henry *et al.* 2010). In tree allometric equations, the relationship between several dendrometric variables have been established for estimating wood biomass (Chave *et al.* 2005; Henry *et al.* 2010; Henry *et al.* 2013). Most equations use either DBH alone or DBH and height or DBH, height and the specific gravity of wood as variables to estimate tree biomass.

The equation 1 suggested by Chave *et al.* (2005) for the moist forest stands is the most relevant equation for the study sites and used to estimate AGTB because : a) the equation was developed using a large dataset (with >5 cm DBH trees) including Asian forests; b) the equation uses three variables i.e. wood specific gravity, tree height and DBH (all of three variables are important determinants of the carbon quantity); 3) the equation has been tested in a variety of climatic situations and different equations have been recommended for specific climates; 4) the study sites fall under the moist category of forests with average annual rainfall exceeding 1,700 mm during 1976–2005 (Marahatta *et al.* 2009) and more than 1990 mm in 2011, and the sites receiving rainfall in most months with few exceptions (DHM 2013). This allometric equation was used to estimate AGTB in other studies related to carbon accounting (Chave *et al.* 2008; Mani & Parthasarathy 2009; Sharma *et al.* 2010). Most importantly, the Ministry of Forests and Soil Conservation Nepal has recommended this equation be used to estimate tree biomass and it is included in the forest carbon measurement guidelines, which were developed together with forestry experts working in the REDD+ activities in Nepal (MFSC 2011).

The equation suggested by Chave *et al.* (2005) for the moist forests which was used in this study is:

$$AGTB=0.0509*\rho D^2H \quad \dots\dots\dots\dots\dots(1)$$

Where,

$AGTB$ = aboveground tree biomass [kg];

ρ = wood specific gravity [gcm^{-3}];

D = tree diameter at breast height (DBH) [cm]; and
H = tree height [m].

Of the three variables required for equation (1), two variables (i.e. diameter and height of the trees) were obtained from the inventory data while the wood specific gravity of all the tree species was obtained from Nepal specific publication (MPFS 1988) (Table 3.3).

Table 3.3 Wood specific gravity used in analysis

Species	Specific gravity (gcm^{-3})
Sal (*Shorea robusta*)	0.88
Botdhangero (*Lagerstroemia parviflora*)	0.85
Saj (*Terminelia tomentosa*)	0.95
Guras (*Rhododendron arboreum*)	0.64
Chilaune (*Schima wallichii*)	0.69
Khote sallo (*Pinus roxburghii*)	0.65
Katus (*Castanopsis spp*)	0.74
Other species found in tropical forests	0.72
Other species found in sub-tropical and lower temperate forests	0.59

The AGTB values of all individual trees within a plot were estimated separately and added to calculate the total AGTB in that particular plot. The sum of all the individual tree biomass values (in kg) of a sampling plot was divided by the area of a sampling plot (250 m^2). This gives the biomass of a plot in kg/m^2, which value was then converted into megagrams per hectare (Mg /ha). Finally, total estimated AGTB of the plot was converted into carbon stock by multiplying by the carbon fraction 0.47 which is recommended for whole trees (IPCC 2006) and used in other biomass carbon studies (Gibbs *et al.* 2007; Zanchi *et al.* 2013)

Above ground sapling biomass (AGSB)

The Nepalese specific biomass table was used to estimate AGSB. Although biomass table for mid-hill forests were discussed in Thompson (1990), biomass tables developed by Tamrakar (2000) are more applicable in this study. This is because the table developed by Tamrakar (2000) was particularly for community forests of Nepal and gives green biomass for various species with different tree diameters. There were missing biomass data for some species; therefore, values recommended for mixed vegetation types were used. After estimating the green biomass of saplings, this value was then converted into dry biomass by multiplying by the species-wise conversion fraction (dry weight to green weight ratio). Species-wise dry (weight after deducting moisture content) to green weight ratio was taken from the relevant literature (Table 3.4). For saplings for which a fraction was not available in the literature, mean values of closely related species were used as suggested in the literature (Baker *et al.* 2004; Ngugi *et al.* 2011). Average values for trees of the same Family were used; for example: the average value of *Pinus wallichiana* and *Pinus roxburghii* was used for *Tsuga* spp.; the value of *Alnus nepalensis* for *Betula* spp.; the value of *Lyonia ovalifolia* for *Rhododendron* spp.; and the value of *Albizia* for *Dalbergia sisoo*.

Table 3.4 Dry to green weight ration used to convert green biomass to dry biomass of sapling

Tree	**Dry to green weight ratio***	**Source**	**Information source (Forest types)**	**Study area (country)**
Pinus roxburghii	0.58	Shrestha *et al.* (2006)	Sub-tropical forests	Central Nepal
Alnus nepalesnsis	0.57	Shrestha *et al.* (2006)	Sub-tropical forests	Central Nepal
Shorea robusta	0. 517	Jain & Singh (1999), Kataki & Konwer (2002)	Tropical	Central and North east India
Terminalia tomentosa	0. 50	Jain & Singh (1999)	Sub-tropical forests	Central India
Lyonia ovaliforlia	0.613	Jain & Singh (1999)	Sub-tropical forests	Central India
Albizzia lebbeck	0.537	Kataki & Konwer (2002)	Tropical and sub-tropical	North east India
Pinus wallichiana	0.45	Kataki & Konwer (2002)	Sub-tropical	North east India
Schima wallichi	0.545	Bhatt & Tomar (2002)	Sub-tropical and lower temperate	North east Indian mountain
Quercus spp	0.627	Kataki & Konwer (2002)	sub-tropical and lower temperate	North east Indian mountain

Note: *Dry to green ratio was obtained from the relationship between fresh weight immediately after cutting and constant weight obtained with laboratory drying at 103± 2 °C.

Below ground tree biomass (BGTB) and below ground sapling biomass (BGSB)

At present, the above ground biomass estimation method is well developed compared to below ground root biomass estimation (MacDicken 1997). However, root biomass has been considered as an important carbon pool to be included in the carbon accounting process (Hertel *et al.* 2009; Kenzo *et al.* 2010). As observing and measuring root biomass in forests is difficult (Vogt *et al.* 1998; Titlyanova *et al.* 1999), a relationship between shoot biomass and root biomass has been identified and used to estimate belowground root biomass (Cairns *et al.* 1997; Mokany *et al.* 2006). Root to shoot ratio is different according to climatic and physiographic factors of forests (Cairns *et al.* 1997), therefore this study has used two different ratios according to altitude. This is because altitude affects the vegetation type, temperature, soil type and humidity of a particular site (Jackson 1994; Leuschner 2000; GoN 2002). Mokany *et al.* (2006) has identified different ratios for different forests. Above ground biomass was multiplied by 0.27 for the forests located below 2000 m altitude, as suggested for tropical and subtropical forests (Singh and Misra 1979 cited in IPCC 2006), and 0.3 for forests above 2000 m altitude, which was the average for temperate broad leaf and temperate conifer forests identified by Mokany *et al.* (2006). It also represents various sites, vegetation types, live and dead roots, both healthy and unhealthy trees (Mokany *et al.* 2006); therefore, average ratios were used to convert average shoot biomass to average root biomass in plots. These ratios have been suggested by IPCC (2006) for use in national GHG inventories.

Litter biomass (LB) and herb biomass (HB)

The biomass of both litter and herbs was estimated separately from: (1) the fresh weight of samples in a plot; (2) the dry-weight and fresh-weight ratio of samples (in which the dry weight of samples was obtained using oven dry methods in the laboratory); and (3) the sample plot area to hectare expansion factor (the area of a hectare/area of a sample plot) as shown in equation (2)

$$B = w_{fresh} * r * ha\ Expansion \qquad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (2)$$

where;

B = biomass of leaf litter or herb [Mg/ ha];

w_{fresh} = weight of the fresh field sample measured in plot [Mg];

r = ratio of oven dry-weight of sample to fresh weight of the sample (dimensionless); and

$ha\ Expansion$ = hectare expansion factor [area one hectare/area of plot] [ha];

Total biomass/carbon

Total biomass was estimated by adding all individual biomass pools (AGTB, AGSB, BGTB, BGSB, LB and HB). Total biomass was converted into carbon by multiplying by the carbon fraction 0.47 (IPCC 2006) and later converted into CO_2 equivalent by multiplying by 3.667 (the ratio of the molecular weight of carbon dioxide (44) to carbon (12)).

Carbon stock in dominant vegetation types

Biomass carbon data in all sample plots were grouped by vegetation type. Average biomass carbon in the reference year 2010 and changes in biomass carbon (2010–2013) in each forest type were estimated.

Carbon stock for individual CFs

Since sample plots were representative of forests, the total carbon stocks estimated within sample plots were extrapolated to derive the total carbon stock of CFs. Species types differ in CFs with altitude and canopy differences (Garkoti & Singh 1995; Alves *et al.* 2010;). Therefore, the average carbon stock for each canopy type (i.e. <70% and ≥ 70%) within each altitude category (i.e. <1000 m, ≥1000–2000 m and ≥2000 m) was estimated from plot data. Total carbon stock in a particular CF was estimated from carbon stock for each forest category and area of that forest type category within a CF.

Species dominated CFs were identified on the basis of the proportion of areas of dominant vegetation types. For example, if the majority area of a CF was *Schima-Castanopsis* vegetation, the forest was categorised as *Schima-Castanopsis* type.

Carbon stock changes in CFs by REDD+ project activities was estimated adopting the stock difference method of the IPCCC (2006). This was estimated from two times within the carbon stock data (i.e. at reference year in 2010 and after project interventions in 2013) and the time difference.

3.4. Method used to analyse potential growth of carbon stock in CFs

Potential growth of biomass carbon in natural forests without anthropogenic disturbances and average biomass carbon growth under community management have been estimated to understand the gap between these two forest management regimes. Forests exhibit natural growth patterns in an undisturbed condition (Oliver & Larson 1990) while these trends can be distorted by human activities in CFs. Growth patterns by age of stands were estimated. In this analysis, both the above and below ground biomass of trees and saplings were considered because these two contribute most to the total biomass carbon in forests (Finér *et al.* 2003; Turner *et al.* 1995).

3.4.1. Estimation of biomass carbon in undisturbed forests in *S. robusta* forests

There are several models developed for forest growth estimation but the local empirical model was used due to the availability of data for parameters and the potential future application of the study. In order to estimate the “theoretical maximum” or “technical potential” growth of biomass carbon, the yield table (stem volume) developed for natural uniform *S. robusta* forests in Terai in Nepal

(Rautiainen 1995) was used. The model used data generated from a fully stocked *S. robusta* stand (<20% other species) under undisturbed conditions (Rautiainen 1999; Rautiainen *et al.* 2000). The model data has also been adopted in other studies (Gautam & Devoe 2006; Sapkota & Meilby 2009) and the climate of the experimental plots used in the model is similar to the *S. robusta* dominated forest sites in this study (Kayerkhola, Chitwan and Ludikhola, Gorkha). The age of the *S. robusta* trees in this model refers only to the age after die-back phase and 10–25 years of dieback age was not considered (Rautiainen 1995).

Above ground stem volume was converted to biomass carbon by multiplying by the wood density of *S. robusta* (0.72) as suggested in the literature (FAO. 1997; Reyes *et al.* 1992) then the carbon fraction. This stem biomass carbon was then converted into total AGB carbon by multiplying by 1.59. This Biomass Expansion Factor (BEF) was used to estimate the total biomass for *S. robusta* forests in India where trees with diameters from 5 to 80+ cm were available (Haripriya 2000). A similar BEF (1.6) was found in tropical broad leaf forests in Costa Rica (Segura & Kanninen 2005). Total biomass carbon was then estimated by adding the AGB and BGB values. As mentioned, BGB was estimated from the root to shoot ratio. The total biomass carbon (Mg/ha) by age was then plotted to show the patterns of carbon growth of natural undisturbed *S. robusta* forests.

3.4.2. Estimation of carbon stock growth in *S. robusta* forests under CF

The growth pattern of trees follows a sigmoid curve (Weiner & Thomas 2001); therefore the increase in biomass carbon with age follows a similar pattern. Time series field data are needed to derive such a growth curve (Foody *et al.* 1996); however, the collection of time series data is generally not feasible due to financial and resource constraints and many researchers have instead used chronosequences (van Kanten *et al.* 2005; Gehring *et al.* 2005; Dhakal 2013;). Therefore, this study used chronosequence plots of *S. robusta* dominated stands and analysed these to see the growth patterns. The study assumed that the chronosequence plots were derived from similar ecological and climatic conditions and there is minimum natural variation between plot characteristics.

Age and biomass carbon stock (tree and sapling) in plots were presented separately according to canopy types (dense and sparse). In order to identify the 'best fit' model and its parameters, data (total tree biomass carbon and age of dominant trees in respective plots) collected from *S. robusta* dominated forests were fitted into the CurveExpert 2.0 software. CurveExpert is a comprehensive curve fitting system which models X and Y data using a toolbox of linear regression and nonlinear regression models (Kuehne *et al.* 2014; O'Brien *et al.* 2014). This software has inbuilt models that can be used to compare the models and choose the best curve. The software helps to analyse data and identify parameters for the models (Jia *et al.* 2014). A best fit model was selected to estimate the growth patterns in the particular forests. In order to select the 'best fit' model, all biomass carbon estimates in the plots by average age of the dominant trees in both dense and sparse forests were grouped and non-linear regressions (between the carbon stock and age) run using the software. In total, six models (Logistic model, Richards's model, Gompertz model

Weibull and Morgen-Mercer- Flodin (MMF)) were found to explain sigmoidal growth curves in both dense and sparse forests. Among them, the best performance of the models was estimated by comparing differences in the coefficient of determination (R^2). If two or more models had similar R^2 value, the less complicated model (i.e. having fewer parameters) was chosen (Perrin *et al.* 2001).

After selecting the best fitted model, potential biomass carbon growth in dense and sparse CFs by age was estimated. The biomass carbon growth patterns (mean annual increment-MAI, current annual increment-CAI and cumulative increment by age) in CFs were compared with carbon accumulation in undisturbed forests. As mentioned in the literature, CAI and MAI are used in forest management (Davis *et al.* 2001; Powers 2001), where MAI is the average annual increase in biomass carbon of forest stands up to the specified age and the CAI is increase in biomass carbon in a single year (Powers 2001). Similarly, area under the curve was estimated by using the CurveExpert 2.0 for all undisturbed, dense and sparse forest stands to assess differences (the gap) in biomass carbon growth between forest categories.

3.4.3. Gap in carbon stock in CFs with mix broadleaf, *Schima-Castanopsis*, *Pine* and *Rhododendron-Quercus* forests

There are limited publications available regarding carbon stock in undisturbed forests by age for mix broadleaf, *Schima- Castanopsis, Pine* and *Rhododendron-Quercus* forests; therefore, the potential carbon stock increment in dense and sparse canopy forests in these vegetation types were estimated by comparing highest and lowest carbon stock values among the sample plots. As suggested by Tol (2008) and Bornmann *et al.* (2013), estimated maximum and minimum carbon stock data were converted to percentiles to facilitate ranking.

The 90th percentile carbon value in sample plots was estimated and considered as being the maximum growth potential of CFs whereas the 10th percentile carbon value in the sample plots was treated as the minimum level of carbon stock in the forests. Although this is not the technical potential stock, this could indicate potential space available for growth in CFs.

3.5. Methods used to analyse demographic data, forest management practices, changed behaviour and costs and benefits consequences of CFUGs for the REDD+

This study used document review and social research methods namely focus group discussion (FGD) and key informant survey to collect demographic data, forest management practices, change practices and cost and benefits of CFUGs for the REDD+. The following sections give details about each method:

3.5.1. Review of relevant documents

CFUGs, project implementing organisations (ICIMOD, ANSAB, FECOFUN), the department of forests and district forest offices are agencies that potentially are able to maintain the various documents related to forest management decisions, activities and outcomes. In order to collect data related to forest management and socio-economic activities at all 105 CFUGs, a list of relevant documents was prepared. Among them, baseline studies and project progress reports were collected from project implementing organisations; CFUG constitutions, operational plans, monitoring reports and district forest resource related publications from the department of forests and district forest offices as well as meeting decisions and activity records from community forest users committees. These documents provided information related to demographic overview, changes in the condition of forests and management and use practices. A separate checklist was developed and used to collect data related to general information of CFs and costs and benefits to communities for REDD+ (Appendix B and Appendix C). Annual costs and benefits of CFUGs related to forest management were collected for six consecutive years; i.e. three years before and 3 years during the REDD+ (2006–2012). Before requesting these documents and data, a clear explanation about the research purpose (i.e. purely academic) of the study and assurances of confidentiality of the data and its anonymous use were given.

3.5.2. Focus group discussion

FGD is considered a more active and dynamic social discussion which provides opportunities to achieve a cumulative understanding of the identified problem (Kitzinger 1994; Tashakkori & Teddlie 2003). This is popular among social scientists when conducting applied research (Stewart *et al.* 2007). This study used the FGD discussion method with two categories of participants; i.e. representative members of CFUGs by dominant vegetation type and with CFUG executive committees. These were carried out from December 2011 to March 2012.

As mentioned by Kitzinger (1994) and Stewart *et al.* (2007), the study conducted 12 FGDs (i.e. 3 in each vegetation dominated CFs with random selection) to explore reactions and experiences of people for REDD+. Following the method of other studies, 9–15 individuals representing all types of members (including executive committee member, ethnic people, female) were invited to a group discussion (Adhikari *et al.* 2004; CFD/DoF 2009; Maskey *et al.* 2006). From these FGDs, the perceptions of communities regarding changed behaviour due to REDD+ activities, perceptions on forest management, cost and benefits for REDD+, factors affecting carbon stock change in CFs and suggestions for making the REDD+ effective were collected using a checklist (Appendix D). The checklist was developed by including all possible factors, tested in the field and revised to make sure that tool would adequately capture all data. The final revised tools were used to facilitate discussions in a logical flow.

As suggested in the literature (Tashakkori & Teddlie 2003), FGDs with executive committees in all 105 CFUGs were organised to collect complementary information to the data obtained from the documents review method and also for triangulation. Some of the required data, such as quantitative data about grass, litter and firewood collection as well as grazing at CFUGs (Appendix B and Appendix C), were not available in the documents, in which cases FGD data were used in analysis. It was assumed that communities have knowledge about activities and practices even if this has not been recorded.

3.5.3. Key informant survey

A key informant survey is taken as a reliable method to get accurate information (Miller & Cardinal 1994). This was done by involving 20 individuals who were working in CFs and the REDD+ project. Among them, five individuals were from government, five from non-governmental organisations, five from local leaders (including teachers and CFUG leader) and five forest based enterprise workers. These people provide more information and deeper insights about issues from their personal skills, positions and experiences (Marshall 1996) and are generally consulted in CF related studies (Dongol *et al.* 2002; Richards *et al.* 2003; Springate-Baginski *et al.* 2003; Maskey *et al.* 2006; Adhikari *et al.* 2007; Sapkota & Odén 2008). A list of major factors or drivers responsible for reducing biomass in CFs (directly or indirectly) was prepared by reviewing the relevant literature (Appendix A) and provided to key informants for comment and to finalise the list of relevant factors in the study areas as in other studies (Elmendorf & Luloff 2001). Then they were administered in focus group discussion.

3.6. Methods used to analyse factors affecting carbon stock changes

A change in the level of individual factors was compared with changes in carbon stock in CFs (by vegetation types) with the REDD+ project intervention. The final list of relevant factors of the study areas and analysis method was as follows:

a. Evidences of change in biomass reducing factors in CFs with REDD+

The frequency of biomass reducing factors (namely forest fire, livestock grazing, fodder collection, firewood collection and timber harvesting) which were observed and recorded in the inventory plots were analysed for each year. The proportion of plots where each incidence was recorded for each year were analysed and plotted as line charts by vegetation type to identify changes after the REDD+ project.

b. Carbon stock in different elevation forests

Elevation of sample plots (m asl) was recorded using GPS during the inventory. The elevation of plots was compared with carbon stock in the reference year (2010) and carbon stock changes (2010–2013) to see possible effects. Scatter plots were developed by canopy cover types (dense and sparse) for all vegetation types to demonstrate the relationship. The relationship was assessed using the coefficient of determination (R^2) in regression models.

c. Carbon stock in different proximity of the forest from motor-able road and from settlement

The distance of sample plots from closely located driveable road was estimated by analysing GIS data. The data related to forest canopy cover and location of forests was obtained from satellite imagery and GPS points from field measurement. Similarly, data related to roads and settlements were obtained from the Department of Survey, Government of Nepal. The locations of sample points, settlements and roads were identified and distances of the plots from closely located roads and settlements were estimated using ArcGIS.

All vegetation-wise plots were grouped into two categories (i.e. 21 plots located at extremely far and 21 at extremely close distances from the road-head) and estimates of average carbon stock in the reference year (2010) and changes in carbon stock between 2010 and 2013 for each category used to analyse the possible effect of proximity from the road head on carbon stock in the forests.

Following the same process, the effect of distance from settlement on carbon stock and change in carbon stock was estimated and compared.

d. Carbon stock in different aged forests

The average age of dominant trees in a forest stand and its relationship with carbon stock in the year 2010 and change in carbon stock from 2010–2013 was compared. CFs were grouped into older and younger age categories by vegetation. Average carbon stock and changes (2010–2013) between older and younger age categories by vegetation type were compared to investigate possible effects.

e. Carbon stock with different socio-economic factors

The effects of possible factors (namely, per capita forest areas, caste heterogeneity, household level landholding, average change in livestock, biogas use, petroleum energy use, biomass extraction (timber and fuel wood), grazing, quantity of grass and fodder collection, and litter collection) on carbon stock and changes in carbon stock in CFs were analysed individually (Table 3.5). All CFs were grouped into two categories (i.e higher and lower scale (value)) of the factor by vegetation type and carbon stocks analysed. Numbers of CFs by dominant vegetation types differ. However, two groups of equal numbers of CFs with higher and lower scales of factors were created for analysis. Therefore, *S. robusta* mix broad leaf dominated CFs were grouped into 10 higher and 10 lower, *Schima-Castanopsis* dominated CFs into 10 higher and 10 lower, *Pine* dominated CFs were grouped into 8 higher and 8 lower and *Rhododendron-Quercus* dominated CFs into 4 higher and 4 lower (Table 3.5).

Table 3.5 Methods used for analysing factors affecting carbon stock and change in carbon stock in CFs

S.N.	Factors	Data source	CF category	Descriptions of analysis
1.	Per capita forest areas	Population and areas of CF from documents	Smaller Larger	Estimated per capita forest in each CF and estimated carbon stock and change in carbon stock of smaller and larger size
2.	Caste heterogeneity	Household number of specific caste group (i.e. Brahmin-Chhetri, Ethnic, Dalit) in a CFUG was collected from community records.	Lower Higher	Estimated caste heterogeneity situation of each CF [the below equation was used which was also used in other similar studies (Sapkota & Odén 2008; Varughese & Ostrom 2001). $A = 1 - \sum_{i=1}^{n} (P_i)^2$ Where, Pi = the proportion of total population in the i^{th} caste group, and A= Caste heterogeneity index, (varies from 0–1, where 0 is perfectly homogeneous and 1 is highly heterogeneous)]
3.	Average household level landholding size	CFUG records and verified from the FGDs	Smaller Larger	As for point 1, estimated average land holding in each CF and estimated carbon stock and change in carbon stock of smaller and larger size
4.	Average change in livestock	Average livestock size in CFUG. Average number of Buffalo, Cow/Ox, Goat in CFs (in per HH) from records and FGD	Change small Change large	1) Estimated average livestock size in CFUG in particular year by using livestock standard units (LSU) in which: 1 buffalo = 1 unit, 1 cow=0.7 unit and 1 goat =0.1 unit (Thapa & Paudel 2000; Thorne & Tanner 2002) 2) Estimated change in livestock size in CF from before (average of 3 years) to after (average of 3 years) the start of the REDD+ project
5.	Biogas use	Biogas using households in each CF from records and FGDs	Lower proportion Higher proportion	Estimated proportion of biogas using households (biogas using HHs/Total HH in CF) in each CF.
6.	Petroleum energy use	Petroleum energy (Liquefied Petroleum Gas and Kerosene) using household in CFs from records and FGDs	Lower proportion Higher proportion	Estimated proportion of Petroleum energy using households (biogas using HHs/Total HH in CF) in each CF.

7.	Biomass extraction*	Total average annual extraction of fuel wood and timber from records and FGD	Less change in extraction More change in extraction	1) Estimated average annual extraction of timber biomass [volume (m^3/yr) was converted into biomass by multiplying by wood density.] 2) Estimated average annual extraction of fuel wood (Bhari) in each CF multiplied by conversion factor (1bhari=30 kg) suggested in Nepal (Neupane 2003; Pokharel 2008) 3) Estimated total annual extraction (sum of both timber and fuel wood) of biomass in each CF 4) Estimated average change in total annual extraction from before (average of 3 years) to after (average of 3 years) the start of the REDD+ project
8.	Grazing	Total number of buffalo, cow/ox and goat grazing in forests for a whole year was collected from records and FGDs	Smaller change Larger change	Annual livestock grazing in CF [Number of each grazing livestock types converted into LSU. Average annual grazing livestock size in each CF was estimated using a conversion factor as stated in point 4 in this table.] Estimated changes in grazing from before (average of 3 years) to after (average of 3 years) the start of the REDD+ project
9.	Quantity of grass and fodder collection	Total annual grass collection in each CF from record (decision to collect) and FGDs	Smaller change Larger change	Converted Bhari to ton [Unit of grass was Bhari in study sites which was converted into tons from the relationship: 1 Bhari=25 kg (Adhikari *et al.* 2004; Sunam 2011)] Estimated changes [Grazing from before (average of 3 years) to after (average of 3 years) the start of the REDD+ project]
10.	Litter collection	Same as grass (point 9 of this table)	Smaller change Larger change	Converted Bhari to ton [Unit of litter was Bhari/Doko which was converted into tons from the relationship: 1 Bhari=20 kg (Adhikari *et al.* 2004; Sunam 2011)] Estimated changes in litter collection from before (average of 3 years) to after (average of 3 years) the start of the REDD+ project

Note: * Among all carbon pools included in this study, trees constitute a major part of the aboveground biomass carbon in forests (Turner *et al.* 1995) and extraction of fuel wood and timber from the forest reduces these stock

3.7. Methods used to analyse trade-off between carbon benefits and community benefits

3.7.1. Costs of CFUGs for REDD+

The trade-off between additional costs to communities (including foregone benefits, effort/contribution made for forest management) for the REDD+ and carbon revenue was analysed to investigate the cost and benefit aspects in REDD+ CFs. Additional costs to communities were estimated from real time cost and benefit differences between 3 years before the REDD+ (July 2006- July 2009) and 3 years during the REDD+ (July 2009- July 12). The estimated cost was compared against possible carbon revenue. The carbon revenue was estimated from carbon stock change (2010–2013) and the expected market price of the carbon credits.

In CFs, forest products extraction and grazing are the main direct benefits to communities (Bahuguna 2000; Adhikari *et al.* 2007; Cooke *et al.* 2008; Sapkota & Odén 2008), while the labour contribution of communities to forest management is the main cost (Bhattarai 2011). The data related to both benefits and contributions were obtained by reviewing records and other documents maintained by communities and projects and FGDs (Table 3.6); these were analysed in the following ways:

Table 3.6 Items and data sources used to estimate real time benefits and costs of the communities in CFs for six year (2006 -2012 i.e. three years before and three years during the REDD+ projects)

	Item heading	**Data collection (annual)**
Benefits	Timber	Reviewed records of CFs and asked species-wise annual total extraction of timber (m^3)
	Grasses	Asked annual collection (Bhari)
	Fodder	Asked total annual collection of fodder in CF (Bhari)
	Litter	Asked annual quantity collection in CF (*Bhari*)
	Fuel wood	Reviewed records of CFs and asked annual collection of fuel wood (*Bhari*)
	NTFPs	Total annual income from records
	Livestock grazing (buffalo, cow, goat)	Asked annual total number of buffalo, cow and goat grazing days in CF and Additional grass required for one day during stall feeding livestock
Contribution	General assembly	Reviewed records of annual total man-days and other related cost in CF
	Executive committee meeting	Reviewed records of annual total man-days and other related cost in CF
	Plantation	Reviewed records and asked annual labour and other materials cost in CF
	Forest fire control	Reviewed records of annual labour and other materials cost in CF
	Silviculture operation	Reviewed records of annual labour and other materials cost in CF
	Harvesting of forest products	Reviewed records and asked annual costs in CF
	Guarding	Reviewed records and asked annual labour cost in CF

a) Costs of communities due to changed forest product use behaviour or sacrificed benefit for REDD+

Although the fundamental aim of CF is to provide forest products for subsistence needs and improve forests, forest product use practices may have changed with the REDD+ project. These changed practices have added costs to communities which were estimated to determine sacrificed benefit. The annual quantity of all forest product use in each CF was collected for all 6 years and changes in the quantities of forest product harvested were estimated from the difference between the average of annual quantity of harvest in the 3 years before the REDD+ and the average of annual harvest during the 3 years of REDD+ project period. Total changed benefits were estimated by multiplying the change in quantity by a per unit price. The study used the 2012 price to estimate the changes in relation to the latest value. Similarly, change in contribution was estimated from the average of annual contribution cost (i.e labour and material cost).

The unit prices of timber, firewood, grasses, fodder and litter in year 2012 were different in sites (Table 3.6). Timber prices were highest for *Shorea robusta* and less for other timber trees (Pine, *Schima* and *Castanopsis*). Prices were collected from 15 random individuals from each study site and the average used. Local sawmill owners and carpenters were the key respondents for timber prices while local restaurants and firewood sellers provided firewood prices. Sawmill owners and carpenters were less than 15 in number in all three sites therefore local people who were familiar with the timber business were also consulted. Similarly, prices per unit of grasses *(Bhari)*, fodder (*Bhari*) and litter (*Bhari/ Doko)* were asked from 15 local people at each site and the average used. Although grasses, fodder and litter were not commonly sold in the study areas, the price was estimated from willingness of communities to buy a unit of product and/or considering the time value required for collection from the forests.

Table 3.7 Unit price of forest products in 2012 in the study areas

Forest product	**Price (US$) in 2012**		
	Gorkha	**Chitwan**	**Dolakha**
Timber (per m^3) -*Shorea robusta*	1221.47	1495.67	0.00
Dalbergia sissoo	0.00	373.86	0.00
Terminalia alata and *Adina cordifolia*	0.00	274.16	0.00
-Other spp**(per m^3)	186.96	207.73	207.73
Fire wood per Bhari	1.80	2.35	1.76
Grass/fodder per Bhari	1.30	1.42	1.30
Litter per Bhari	0.71	0.82	0.71

Note: 1 US$= 85 NRs (exchange rate of 2012); ** other spp includes *Schima wallichii*, *Pinus* spp, *Alnus nepalensis,*

In the case of NTFPs, CFUGs sell them and gain income. Total annual incomes of each CF from the NTFPs were collected from community records.

Grass and fodder requirements are higher for buffalo, followed by cow/ox and goat, respectively (Das & Shivakoti 2006). The price of grazing benefit in each year in CFs was estimated for each livestock type (Buffalo, cow/ox, goat) by identifying additional grass required to feed each livestock during a non-grazing day and the price of the grass. During group discussions, total grass required for individual buffalo, individual cow/ox and individual goat in a day during grazing day and non-grazing day was asked. Those differences provided the total additional quantity of grasses required for each individual livestock type during a non-grazing day. Separate estimation of costs was made for each livestock type (buffalo or cow/ox or goat) and added to get the total cost in CF due to stall feeding. For example, total added cost due to stall feeding of buffalo was estimated by multiplying the total annual non-grazing days of additional buffalo used in a CF for REDD+, the additional units of grass required for those buffalo during a non-grazing day and the unit price of grasses. A similar process was followed for ox/cow and goat.

b) Cost of CFUGs due to reduced forest product harvesting practices for REDD+

With reductions in the quantity of forest products harvested to increase REDD+ carbon benefits, CFUGs had reduced the cost of harvesting. The reduced harvesting cost was a benefit to CFUGs. In hill areas, individual members of CF who need timber themselves do harvesting and logging and pay the required costs. Therefore, hill CFUGs have no institutional harvesting costs applied before or after the REDD+ project. In contrast, CFUGs in terai harvest timber and distribute it to those individuals who need it. Therefore, harvesting costs were considered only for terai CFs. Annual labour costs and other material costs incurred for timber harvesting in each terai CF were collected. The difference between the average cost (3 year before and 3 year during REDD+ project) of timber harvesting in terai CFUGs (i.e. Kayerkhola) were estimated to investigate any changes.

c) Cost to communities due to changed forest management activities or changed contribution for REDD+

Man-days (wages) and other cost (foods and materials) spent for GAs and executive committee meetings, plantation, forest fire control, silviculture operation, and guarding activities were analysed for individual CFs for each year. As for the forest products prices, the wage rates of year 2012 were used to estimate the total changed value of contributions for the REDD+ project. Although communities have different skills, they could have different opportunity costs. However, CFUGs have set practices that they schedule meetings and GAs during free time for the majority of people (that includes days off for the job holders). Furthermore, the majority of participants are farmers and there are limited opportunities for income and paid jobs in rural areas. Therefore, the study assumed the same opportunity cost equivalent to agricultural labour for both skilled and non-skilled participants. Average wage rates (in 2012) for the study areas were estimated from 15 random respondents from each district.

3.7.2. Analysis of total costs and carbon benefits in REDD+ CFs

The total real time costs or sacrificed benefits of each CF for REDD+ was estimated by adding the costs for changed forest products use and costs for changed forest management practices, and subtracting added benefits. In many studies, a per hectare basis is used for carbon stock estimation for forests (Tan *et al.* 2010; Maraseni *et al.* 2010; Maraseni & Cockfield 2011; Maraseni & Xinquan 2011); therefore all net sacrificed benefit or cost of communities are converted into a cost per hectare basis. Similarly, estimated carbon stock changes in CFs by species dominated forests are also converted into carbon dioxide (CO_2) equivalent per hectare to understand community added costs for each unit of carbon stock increment.

3.7.3. Carbon gain estimation in CFs

The study used the 100 year time horizon rule to estimate carbon sequestration potential in CF. Actual CO_2 sequestration from the atmosphere in the forests was estimated by dividing the total estimated carbon by a constant 100 (Fearnside 1997). The 100 year time horizon is a timeframe over which temporary carbon must be stored in a forest to be considered equivalent to a permanently avoided emission (Costa & Wilson 2000; Fearnside 2000; Fearnside 2002). This is important in forestry projects because there is uncertainty about carbon saving in forestry. Trees can easily be cut or burned so that their accumulated carbon is re-released. However, this is not so in the case of energy projects which save fossil fuel usage and avoid related emissions permanently in a sense that if once saved, they can never be lost again. Therefore carbon estimation in forestry related carbon projects need some adjustments within a time horizon. In forestry projects, 100 years could be a reasonable timeframe to ensure permanence (i.e. longevity of a carbon pool and the stability of its stocks under the given management and disturbance environment in which it occur) which was discussed for GHGs emissions estimation in different literatures (Fearnside 2002; IPCC 2006; Maraseni 2007; UNFCCC 2007; Kollmuss *et al.* 2008).

3.7.4. Price used in carbon revenue estimation

Compliance markets (mandatory and regulatory that include CDM and EU-ETS) and voluntary carbon markets (non-regulatory but operate with agreement between seller and buyer) are now functioning to offset GHGs emissions. The market price of carbon stocks on these markets fluctuates. During the first commitment period of the Kyoto protocol (2008–2012), prices were higher at the beginning and lower in later years. The CDM market price was US$23/$MgCO_2$e in 2008 (Capoor & Ambrosi 2009) and fell to US$0.26/$MgCO_2$e in 2013 (World-Bank 2013). On the voluntary market, carbon price ranged from US$1.20–46.9/$MgCO_2$e in 2008 (Hamilton *et al.* 2009) and US$5.90/$MgCO_2$e in 2013 (Peters-Stanley & Yin 2013). Though the European Union Emission Trading Scheme (EU-ETS) does not accept forestry sector carbon at present, there is the possibility this will be included in future schemes;

EU-ETS had higher prices (i.e above \$45/MgCO$_2$e ton) in 2008 which also fell (i.e \$6/MgCO$_2$e) in 2013.

In addition to the CDM and the voluntary mechanism for afforestation and reforestation projects, the REDD+ mechanism is evolving as a market mechanism. The REDD+ mechanism was initiated as a voluntary market mechanism and one of the pilot projects was offered US\$7–8/MgCO$_2$e for forward credit in 2013 (World Bank 2013). However, this price may not compensate all costs, global negotiations are striving to bring better incentives to those REDD+ projects which are generating both environmental and socio-economic benefits. This is more likely to get priority for the carbon credits generated particularly in community managed forests of least developed countries and may generate a premium price. Three assumptions have been made in this study and three possible prices used for carbon credit revenue; 1) an optimistic situation for a better future carbon market mechanism giving priority to CF (securing biodiversity and community socio-economic aspects); an optimistic price of US\$20/MgCO$_2$e was used; 2) continuing with the present situation with REDD+ carbon credits priced as mentioned in World Bank (2013); a price of US\$7/MgCO$_2$e was used; and 3) a worst situation of the carbon market which assumed that REDD+ CFs got the lowest value mentioned in the range of voluntary market prices; a price of US\$1.2/MgCO$_2$e was used for analysis.

3.8. Conclusions

This chapter described the complete methodology adopted for this study. In order to achieve the goals of the study, both primary and secondary data were analysed. The primary data used included carbon pools, biophysical and socio-economic aspects of CFs, and changed practices of CFUGs for REDD + projects. Similarly, the specific gravity of tree species, dry to fresh weight ratio or moisture content in the wood of various tree species, default values and ratios for carbon fraction and above to below ground ratio and data analysis techniques were taken from the relevant literature. Methods used to analyse the distribution of different sized trees, estimate carbon stock and change in carbon stock, estimate gaps in current CFs compared with the potential growth of the forest without disturbance, analyse factors and their possible effects on carbon stock and change in carbon stock in CFs and analyse trade-off between community foregone sacrificed benefits and carbon gains were presented. All of these analyses were made by dominant vegetation types. Results of the analysis are presented in the following chapters.

CHAPTER FOUR

DYNAMICS OF CARBON STOCK IN REDD+ COMMUNITY FORESTS

4.1. Introduction

Chapter 3 discussed the methodology used in this study. This chapter presents the dynamics of distribution of different size trees, carbon stock and changes in carbon stock in the study area REDD+ CFs. The chapter focuses on results associated with two questions: What is the present distribution pattern of trees by diameter size class in REDD+ CFs? What is the carbon stock and change in carbon stock in REDD+ CFs by vegetation type? It attempts to answer these questions by analysing forest inventory data.

This chapter is divided into different four sections. The next section gives an overview of stocking rates of different sized trees in CFs, the third section gives knowledge of biomass and carbon stock dynamics in the sample plots by dominant vegetation type and the fourth section gives knowledge of biomass and carbon stock in individual CFs by dominant vegetation and the last section concludes the chapter.

4.2. Distribution of different size trees in CFs

Stocking rates of the forests are analysed and presented in Table 4.1 and Table 4.2. Forest vegetation were divided into regeneration (rooted to <1 cm dbh), sapling (≥1–5 cm dbh) and tree (≥5 cm dbh) and analysed by vegetation type.

The inventory for the reference year 2010 showed that regeneration, sapling and tree sized plants were distributed in a pattern of a higher stocking rate of smaller sized plants and gradual reduction towards larger ones. Among five vegetation types, as expected, the highest numbers of regeneration were found in dense forests in all vegetation types except *S. robusta* dominated forests. In *S. robusta* forests, regeneration numbers were higher in sparser strata in year 2010 which could be a result of the species' light demanding characteristics and the open space available to foster seedlings on the forest floor. Similarly, a gradual decrease in the stocking rate of regeneration was found in forests from dominant *S. robusta* vegetation to mixed broadleaf, *Schima-Castanopsis*, *Pine* and *Rhododendron-Quercus* forests. In the case of saplings, these were highest under dense canopy cover in the mixed broadleaf forests, *Schima-Castanopsis* forests and *Rhododendron-Quercus* forests, while in *S. robusta* dominated and *Pine* dominated forests sparse canopy cover tended to have greater stocking rates of saplings. As expected, tree stocking rates in the year 2010 were highest under dense canopy in all forests. Among the different vegetation types, the stocking rate of trees was highest in *S. robusta* forests followed by *Schima-Castanopsis*, *Rhododendron-Quercus*, mixed broadleaf and *Pine f*orests respectively.

Table 4.1 Comparison of stocking rates of woody vegetation by species and their strata in the REDD+ CFs (in year 2010 and 2013) in the study sites

Dominant vegetation type	Type of strata	No of Plot	Stoking rate of Reg[1] (No/ha)		Stoking rate of Sapling[2] (No/ha)		Stoking rate of Tree[3] (No/ha)	
			Year 2010	Year 2013	Year 2010	Year 2013	Year 2010	Year 2013
Shorea robusta	Dense	154	54161	41112	1738	2324	1336	1716
	Sparse	42	58614	47164	2093	2272	1035	1327
	Total	196	55115	42409	1814	2312	1271	1632
Mixed broadleaf*	Dense	53	40260	34071	1281	1647	639	973
	Sparse	10	36943	32803	880	1280	514	824
	Total	63	39733	33871	1217	1588	619	949
Schima-Castanopsis	Dense	98	31815	24991	1815	2565	1082	1597
	Sparse	18	27070	27070	1572	1511	706	1178
	Total	116	31078	25313	1778	2402	1023	1532
Pine	Dense	30	19533	18365	977	1530	642	976
	Sparse	12	11412	16720	1167	2009	503	845
	Total	42	17213	17895	1031	1667	602	939
Rhododendron-Quercus	Dense	60	18153	15605	2370	2485	1066	1467
	Sparse	13	3185	17149	2300	1931	653	920
	Total	73	15487	15880	2357	2386	993	1370
Total	Dense	395	38652	30565	1734	2257	1086	1493
	Sparse	95	36809	33894	1778	1943	798	1129
	Total	490	38295	31211	1742	2196	1030	1422

Note:*species include *Lagerstroemia parviflora* (Botdhairo), *Terminalia* spp, *Anogeissus* latifolia (Bajhi), *Dalbergia* sissoo, *Syzygium cumini* (Jamun); [1]regeneration means woody plants with <1cm dbh; [2]sapling means woody plants with 1-5cm dbh and [3]trees means woody plants with ≥5cm dbbh; dense means forests with ≥70% canopy cover; sparse means forests with <70% canopy cover

After three years of the REDD+ project intervention, there was a negative change in the stocking rate of regeneration found in all forests except sparse *Schima-Castanopsis* forests, *Pine* forests and *Rhododendron-Quercus* forests where numbers increased (Table 4.2). One possible reason behind that increase could be the favourable condition of the forest floor for germination. Open space available in sparse forests admits sunlight and rain water at ground level which may encourage germination and growth of new seedlings. However, sparse canopy types of *S. robusta* forests and mixed broadleaved forests may have had negative changes in regeneration because they already have been abundant in the reference year. Good seed years for particular species could be another reason for such differences in the stocking rates of regeneration and saplings.

A positive change in the stocking rate of saplings was found in all forests with both canopy categories except sparse canopy of *Schima-Castanopsis* and *Rhododendron-Quercus* forests. There could be several reasons for that exception, including: less recruitment of the new saplings with positive changes in regeneration, thinning and cleaning activities of communities; harvesting of smaller sized trees from sparse canopy forests for wooden handled agricultural equipment and fencing in middle and higher altitudes (*S. robusta* is preferred for wooden handles due to its strength; however people harvest *Schima* and *Castanopsis* trees in areas where *Shorea* is not available); and sparse canopy sites were located near walking trails where people could easily harvest and remove smaller trees. The stocking rate of saplings was higher in sparse canopy *Pine* forests followed by dense canopy types of *Schima-Castanopsis* forests which are comparatively fast growing by nature.

The stocking rates of trees increased in all CFs but the increase rates differed (Table 4.2). *Rhododendron-Quercus* dominated forests with sparse canopy had less positive change in tree numbers followed by *S. robusta* dominant sparse canopy forest. This could be due to site quality of forests, slow growth character of the species and the forest products use and management practices of communities. The highest stocking rate of trees was observed in *Schima-Castanopsis* forests which is a fast growing species. Communities may also have changed harvesting practices. Communities were using forest resources to fulfil their daily needs but did harvest trees for timber only if user members needed to build or renovate a house. In general people do not build houses every year so they do not harvest timber trees on a regular basis. *S. robusta* is considered to be a high value timber tree and there was some illegal harvesting by outsiders observed in the forests.

Table 4.2 Comparison of change in stocking rates (from 2010 and 2013) of woody vegetation by vegetation types and their strata in the REDD+ CFs in the study sites

Dominant vegetation type	**Type of strata**	**No of Plot**	**Regeneration[1]**		**Sapling[2]**		**Tree[3]**	
			Change (No/ha)	**SD**	**Change (No/ha)**	**SD**	**Change (No/ha)**	**SD**
Shorea robusta	Dense	154	-13049	35560	586	1703	380	374
	Sparse	42	-11450	27906	179	1653	292	261
	Total	196	-12706	34005	498	1696	361	354
Mixed broadleaf including Sal*	Dense	53	-6189	32570	366	983	334	145
	Sparse	10	-4140	20642	400	1028	310	166
	Total	63	-5862	30857	371	982	330	148
Schima-Castanopsis	Dense	98	-6824	26555	750	1626	515	411
	Sparse	18	0	33615	-61	825	472	349
	Total	116	-5765	27713	624	1555	509	401
Pine	Dense	30	-1168	21265	553	923	334	310
	Sparse	12	5308	20203	842	925	342	173
	Total	42	682	20931	636	922	337	276
Rhododendron-Quercus	Dense	60	-2548	17243	115	1258	401	195
	Sparse	13	13964	10920	-369	1271	267	273
	Total	73	393	17435	29	1265	377	215
Total	Dense	395	-8087	30021	523	1499	407	341
	Sparse	95	-2915	27022	165	1355	331	269
	Total	490	-7084	29508	454	1478	392	329

Note: *species include *Lagerstroemia parviflora* (Botdhairo), *Terminalia* spp, *Anogeissus latifolia* (Bajhi), *Dalbergia sissoo*, *Syzygium cumini* (Jamun); [1]regeneration means woody plants with <1cm dbh; [2]sapling means woody plants with 1-5cm dbh and [3]trees means woody plants with ≥5cm dbbh; dense means forests with ≥70% canopy cover; sparse means forests with <70% canopy cover; SD means standard deviation; - sign means negative changes; no sign means positive changes

4.3. Biomass and carbon stock dynamics in sample plots

Carbon stock and its changes are analysed and presented by dominant vegetation types. Different results were observed in plots by vegetation type in year 2010, 2011, 2012 and 2013 (Appendix F). These data have been further analysed and results for the reference year 2010 and changes with REDD+ intervention are presented in the sub-sections below.

4.3.1. Total biomass carbon in the reference year 2010 and year 2013

Average carbon stock (both above and below ground) was higher in dense canopy forests than in sparse. The quantity of biomass carbon was also found to differ by dominant vegetation type (Table 4.3). CFs with *S. robusta* dominant plots had, on average, higher quantities of carbon stock followed by *Rhododendron-Quercus* forests, *Pine* forests and *Schima-Castanopsis* forests, respectively. Carbon stock in sample plots ranged from 0.6 MgC/ha in sparse canopy *Pine* forests to 345.1 MgC/ha in dense canopy mixed broadleaf forests in year 2010; these values increased in year 2013 (Table 4.3).

The quantity of carbon stock was higher in dense forests than sparse. For example, in *Pine* forests, dense canopy forests had 11.3 to 230 MgC/ha which was 10.7 to 45.5 MgC/ha higher than sparse canopy in year 2010. This increased to 18.4 to 127.0 MgC/ha in year 2013 which is 15.1 to 56.5 MgC/ha higher than sparse forests. These results indicate that carbon stock in CFs can increase with intervention.

Average carbon stock in dense canopy forests of each dominant vegetation type differed significantly ($p < 0.05$) from sparse canopy forests in both years 2010 and 2013 (Table 4.3). Since sparse forest areas were smaller than dense, the numbers of sample plots were also less. Therefore, the Shapiro-Wilks normality test was carried out for sparse category forests before t-tests were conducted for year 2010 data. The test confirmed the normal distribution of samples with p value > 0.05 (i.e. 0.19 for *S. robusta*, 0.59 for mixed broadleaf, 0.11 for *Schima-Castanopsis*, 0.08 for *Pine* and 0.06 for *Rhododendron-Quercus* forests.

Table 4.3 Comparison of biomass C (both above and belowground, in year 2010 and 2013) by vegetation and their strata in CFs in the study areas

Dominant vegetation type	**Type of strata**	**No of Plot**	**Biomass carbon in year 2010**				**Biomass carbon in year 2013**			
			Avg biomass C (MgC/ha)	**Minimum (MgC/ha)**	**Maximum (MgC/ha)**	**P-value**	**Avg biomass C**	**Minimum (MgC/ha)**	**Maximum (MgC/ha)**	**P-value**
	Dense	154	129.9	2.9	326.6		146.8	1.3	364.3	
Shorea robusta (sal)	Sparse	42	89.2	2.3	198.9	0.00	97.8	6.3	203.8	0.00
	Total	196	121.2	2.3	326.6		136.3	1.3	364.3	
	Dense	53	118.0	6.0	345.1		136.9	12.8	356.9	
Mixed broadleaved*	Sparse	10	69.5	8.0	165.6	0.03	79.1	14.7	174.1	0.01
	Total	63	110.3	6.0	345.1		127.7	12.8	356.9	
	Dense	98	95.2	10.8	277.7		116.0	30.4	300.3	
Schima- Castanopsis	Sparse	18	48.3	8.8	126.3	0.00	54.1	9.9	110.9	0.00
	Total	116	87.9	8.8	277.7		106.4	9.9	300.3	
	Dense	30	103.0	11.3	230.6		127.0	18.4	225.3	
Pine	Sparse	12	62.4	0.6	185.6	0.03	70.5	3.3	185.9	0.00
	Total	42	91.4	0.6	230.6		110.8	3.3	225.3	
Rhododendron-Quercus	Dense	60	114.7	21.1	254.8	0.00	121.7	18.8	254.5	0.00
	Sparse	13	48.2	3.7	151.7		54.2	6.4	174.4	
	Total	73	102.9	3.7	254.8		109.7	6.4	254.5	
	Dense	395	115.3	2.9	345.1		132.5	1.3	364.3	
Total	Sparse	95	70.4	0.6	198.9	0.00	78.1	3.3	203.8	0.000
	Total	490	106.6	0.6	345.1		122.0	1.3	364.3	

Note:*species include *Lagerstroemia parviflora* (Botdhairo), *Terminalia* spp, *Anogeissus latifolia* (Bajhi), *Dalbergia sissoo*, *Syzygium cumini* (Jamun)

A pair wise comparison of the probability of having the same mean between different forests by vegetation types and canopy cover types was carried out (Table 4.4). Results indicate that mean carbon stocks in year 2010 differed significantly between dense and sparse canopy samples (within each species dominated forest). Comparison between different dominant vegetation types indicated that the mean carbon stock of each forest category also differed significantly from the mean of at least three other forest categories. These differences were higher in the dense canopy of *S. robusta* forests (i.e. significantly different from six other vegetation types) followed by sparse canopy of *Schima- Castanopsis* and sparse canopy of *Rhododendron-Quercus* forests (i.e. significantly different from five other forests) and lowest in dense canopy of *Pine* forests (i.e. significantly different from three other forests) (Table 4.4).

Table 4.4 Pair-wise comparison of p value (assuming unequal variance, two tail) for having similar mean carbon stock (difference in mean =0) in CFs by vegetation and canopy cover differences in 2010

Dominant vegetation types	*S. robusta* sparse	Mix broadleaf dense	Mix broadleaf sparse	*Schima-Castanopsis* dense	*Schima-Castanopsis* sparse	*Pine* dense	*Pine* sparse	*Rhododendron-Quercus* dense	*Rhododendron-Quercus* sparse
S. robusta dense	**0.00**	0.38	**0.01**	**0.00**	**0.00**	**0.03**	**0.00**	0.17	**0.00**
S. robusta sparse		**0.05**	0.32	0.59	**0.00**	0.32	0.12	**0.05**	**0.02**
Mix broadleaf dense			**0.03**	0.09	**0.00**	0.34	**0.00**	0.82	**0.00**
Mix broadleaf sparse				0.18	0.28	0.11	0.75	**0.03**	0.34
Schima-Castanopsis dense					**0.00**	0.52	**0.00**	0.07	**0.01**
Schima-Castanopsis sparse						**0.00**	0.40	**0.00**	1.00
Pine dense							**0.03**	0.39	**0.00**
Pine sparse								**0.00**	0.47
Rhododendron-Quercus dense									**0.00**

Note: Bold p-value shows significant difference (<0.5)

4.3.2. Change in carbon stock in sample plots in CFs between 2010 and 2013

On average, carbon stock was found to increase between 2010 and 2013 in all forest types in the REDD+ CFs. In plot-wise analysis, the mean of carbon stock changes were higher in dense canopy forest then sparse. Specifically, these changes were higher in dense canopy *Pine* forests followed by dense canopy *Schima-Castanopsis* forests, dense canopy mixed broadleaf forests, and dense canopy *S. robusta* forests, respectively. Among all dense canopy vegetation types, dense *Rhododendron-Quercus* forests showed less increase, while in sparse canopy forests, mixed broadleaf forests showed the highest rate of increase followed by *S. robusta*, *Pine, Rhododendron-Quercus,* and *Schima-Castanopsis* forests.

Changes ranged from extreme values of -29.0 MgC/ha (negative) to 49.6 MgC/ha (positive) in the experimental plots. Higher positive change was estimated in dense canopy *Pine* forests followed by dense canopy *Schima-Castanopsis* forests and *S. robusta* forests, while lower positive changes were estimated in sparse canopy *Rhododendron-Quercus* forests. On the other hand, higher negative changes were found in dense canopy *S. robusta* forests followed by dense canopy *Rhododendron-Quercus* forests, sparse canopy *S. robusta* and dense canopy *Pine* forests. These negative changes were mainly due to forest use provisions and regular silvicultural activities (removal of malformed trees) of communities' excess to yield in many cases except in *S. robusta* forests which is commercial timber tree and illegal activities may also have been going on due to heterogeneous communities and road access.

Similar to the analysis of carbon stock in the reference year 2010, the normality test for changes in carbon stock data was carried out for sparse vegetation. The Shapiro-Wilks test showed those samples were normally distributed in all vegetation types with p-value > 0.05 (i.e 0.47 for mixed broadleaf, 0.07 for *Pine*, 0.09 for *Rhododendron-Quercus,* 0.26 for *S. robusta*, 0.97 for *Schima-Castanopsis*). Comparison of mean changes in carbon stock between canopy covers (dense and sparse) within each vegetation type found significant differences in the majority of cases except between mixed broadleaf forests and *Rhododendron-Quercus* forests (Table 4.5).

Table 4.5 Comparison of changes in biomass C in three year (between 2010 and 2013, both above- and-belowground) by vegetation types and their strata in CFs in the study areas

Dominant vegetation type	Type of strata	No of Plot	Change in biomass C (MgC/ha)	Minimum (MgC/ha)	Maximum (MgC/ha)	SD	P-Value
Shorea robusta	Dense	154	16.9	-29.0	48.5	21.9	**0.02**
	Sparse	42	8.7	-26.4	44.9	19.6	
	Total	196	15.1	-29.0	48.5	21.6	
Mixed broadleaf *	Dense	53	18.9	-20.7	45.2	16.5	0.13
	Sparse	10	9.6	-16.1	41.4	16.7	
	Total	63	17.4	-20.7	45.2	16.8	
Schima- Castanopsis	Dense	98	20.9	-17.4	49.1	16.5	**0.00**
	Sparse	18	5.7	-15.4	27.6	11.5	
	Total	116	18.5	-17.4	49.1	16.7	
Pine	Dense	30	24.0	-21.9	49.6	17.4	
	Sparse	12	8.1	-3.4	27.4	9.7	**0.00**
	Total	42	19.4	-21.9	49.6	17.1	
Rhododendron-Quercus	Dense	60	7.0	-28.0	39.5	16.5	0.77
	Sparse	13	5.9	-16.7	22.7	9.8	
	Total	73	6.8	-28.2	39.5	15.5	
Total	Dense	395	17.2	-29.0	49.6	19.4	
	Sparse	95	7. 8	-26.4	44.9	15.6	**0.00**
	Total	490	15.4	-29.0	49.6	19.1	

Note: *species include *Lagerstroemia parviflora* (Botdhairo), *Terminalia* spp, *Anogeissus latifolia* (Bajhi), *Dalbergia sissoo, Syzygium cumini* (Jamun); Bold p-value shows significant difference (< 0.5)

In pair-wise comparison among dominant vegetation types, mean carbon stock in sample plots of a particular vegetation type were found to be significantly different from others (either with different canopy cover or with different vegetation types) (Table 4.6). Changes in carbon stock in dense canopy *Pine* forests were highly significantly different to those from all other forest types except dense canopy *S. robusta*, *Schima-Castanopsis* dense and mixed broadleaf forests.

Table 4.6 Pair-wise comparison of p- value (assuming unequal variance, two tail) for having similar mean carbon stock (difference in mean =0) for having same changes in biomass carbon in CFs (from 2010 to 2013) by vegetation and canopy cover

Dominant vegetation types	**Shorea sparse**	**Mixed broadleaved dense**	**Mixed broadleaved sparse**	**Schima-Castanopsis dense**	**Schima-Castanopsis sparse**	**Pine dense**	**Pine sparse**	**Rhododendron-Quercus dense**	**Rhododendron-Quercus sparse**
Shorea dense	**0.02**	0.49	0.22	0.10	**0.00**	0.06	**0.01**	**0.00**	**0.00**
Shorea sparse		**0.01**	0.87	**0.00**	0.48	**0.00**	0.90	0.65	0.51
Mixed broadleaf dense			0.13	0.49	**0.00**	0.20	0.31	**0.00**	**0.00**
Mixed broadleaf sparse				0.07	0.52	**0.03**	0.80	0.65	0.54
Schima-Castanopsis dense					**0.00**	0.40	**0.00**	**0.00**	**0.00**
Schima-Castanopsis sparse						**0.00**	0.55	0.73	0.96
Pine dense							**0.00**	**0.00**	**0.00**
Pine sparse								0.74	0.58
Rhododendron-Quercus dense									0.77

Note: Bold p-value shows significant difference (< 0.5)

4.4. Biomass and carbon stock in individual CF

Carbon stock in CFs was estimated from the relationship between the area occupied by a forest type (based on altitude category and canopy category) and carbon stock estimated for that type (Table 4.7).

Table 4.7 Average carbon stock (MgC/ha) in different canopy forests within different altitudes estimated from sample plots

Altitude of different forests by each canopy type in CFs	Carbon stock in 2010 (MgC/ha)	Carbon stock in 2011 (MgC/ha)	Carbon stock in 2012 (MgC/ha)	Carbon stock in 2013 (MgC/ha)
<1000m (≥70% canopy) (N=223)	125.06	133.54	136.32	140.64
<1000m (<70% canopy)(N=66)	74.07	78.79	79.22	82.74
1000-2000m (≥70% canopy)(N=78)	87.40	102.83	110.29	117.09
1000-2000m(<70% canopy) (N=16)	62.93	64.34	70.68	72.57
>2000m (≥70% canopy)(N=94)	115.44	122.68	123.04	126.08
>2000m (<70% canopy)(N=13)	60.76	58.48	58.95	62.65

Comparing the plot-wise analyses for particular forest type, higher carbon stocks were estimated in dense canopy forests than sparse. Among dense canopy forests, forest at altitudes <1000 m had higher carbon stocks in all four years followed by those at altitudes of >2000 m and 1000–2000 m. In sparse canopy types, higher carbon stock was estimated in forests at altitudes of <1000 m followed by 1000–2000 m and >2000 m, respectively (Table 4.7).

For individual CFs, higher carbon stocks were estimated in large *S.robusta* forests in the reference year 2010 and 2013, followed by *Pine* forest, *Schima-Castanopsis* forests and *Rhododendron* forests, respectively. This study estimated different carbon stock within a particular forest type; for example, carbon stock in *S.robusta* dominated CFs ranged from 76.9 to 124.8 MgC/ha in year 2010. Such differences were also evident in the year 2013 (Table 4.8).

Table 4.8 Average biomass carbon (above and below ground, in year 2010 and 2013) in CFs by dominant vegetation types in the study areas

CF by dominant vegetation	Number of CF	Carbon stock in 2010			Carbon stock in 2013		
		Average (MgC/ha)	Minimum (MgC/ha)	Maximum (MgC/ha)	Average (MgC/ha)	Minimum (MgC/ha)	Maximum (MgC/ha)
Shorea forest	37	114.1	76.9	124.8	128.5	86.8	140.4
Schima-Castanopsis	43	86.0	62.9	123.1	101.6	72.6	138.4
Pine	16	89.0	63.9	122.9	106.6	74.3	138.3
Rhododendron-Quercus	9	77.4	62.9	98.5	88.0	72.6	106.9

Since each CF encompasses multiple categories of forest patches, vegetation categories were grouped on the basis of dominant vegetation type in terms of area coverage. All CFs had positive changes in carbon stock but the estimated levels of changes differed. Annual changes in biomass carbon in CFs were highest in *Pine* forests followed by *Schima-Castanopsis* forests and lowest in *Rhododendron-Quercus* forests. The study showed the changes varied from 1.9 to 9.7 MgC/ha in a year (Table 4.9 and Appendix F). This indicates that the rates of carbon stock change in the CFs can increase with appropriate interventions. Communities were implementing a range of forest management activities and these, and the use of forest resources, might need review to plan for better intervention.

Table 4.9 Change in biomass carbon (above and below ground, between 2010 and 2013) in CFs by dominant vegetation types in the study areas

CF by dominant vegetation	Number of CF	Annual change	Minimum (MgC/ha)	Maximum (MgC/ha)	SD
Shorea forest	37	4.7	3.0	5.2	0.5
Schima-Castanopsis	43	5.1	2.0	9.7	2.1
Pine	16	5.8	2.1	9.4	2.5
Rhododendron-Quercus	9	3.3	1.9	5.6	1.3

4.5. Conclusion

Forest type and canopy cover differences maintained different quantities of biomass carbon stock and exhibited different increment rates with REDD+ activities. Dense canopy forests had the highest density of trees and therefore maintained a higher carbon quantity in the reference year 2010 compared to sparse canopy forests. In term of increments, all CFs across the pilot REDD+ project sites contributed to increases in carbon stocks; however, both total carbon stock and the carbon increments varied by vegetation types. The CFs with *S. robusta* and mixed broadleaf forests were shown to have higher carbon stocks than either *Schima-Castanopsis* or *Pine* forests in the reference year of the REDD+ project. However, average increments in carbon stocks after the REDD+ activities were highest in *Pine* and *Schima-Castanopsis* dominated forests than others. This shows that *Schima-Castanopsis* and *Pine* forests are able to get greater benefit from the REDD+ project in terms of additional carbon benefits.

In plot wise analysis, some plots showed a reduction in biomass carbon in the years following implementation of the REDD+ project. This shows that there are still forest biomass extraction activities going on in the forests as per the provisions and practices stipulated in the operational plans of CFUGs. However, in case of *S. robusta* forests, being commercial species illegal activities might have contributed to some extent in reducing biomass stock. If CFUGs could stop such activities, they would be able to produce more biomass carbon in their forests. But consideration of community forest resource needs and possible alternative means of accessing these may be needed before such action. In the next chapter, the potential growths of carbon stock in CFs are investigated to identify gaps in present carbon stock in CFs.

CHAPTER FIVE

POTENTIAL BIOMASS CARBON GROWTH IN COMMUNITY FORESTS

5.1. Introduction

The previous chapter presented results for stocking rates, carbon stock and change in carbon stock of the different forest types in the study. The overarching goal of this chapter is to analyse the gap between carbon stock growth under undisturbed natural conditions (i.e. “technical potential growth”) and growth under CFs. This information is important in designing REDD+ projects in CFs. This chapter describes the current annual increment (CAI), mean annual increment (MAI), cumulative biomass carbon in both undisturbed forests and CFs (both dense and sparse canopy types).

The chapter has been divided into four sections. The next section gives the technical potential biomass carbon in *S. robusta* forests, the third section covers biomass carbon growth in CFs for all other vegetation types and the final section concludes the chapter.

5.2. Technical potential biomass carbon in *Shorea robusta* forests

5.2.1. Biomass carbon stock in undisturbed forests

The growth rate of biomass carbon is highest at the early stage of tree growth and least at older ages in undisturbed *S. robusta* forests (Figure 5.1). However, total carbon stock in this study was 807.69 Mg/ha at age 80 but only 76.53 Mg/ha at age 9. The Mean Annual Increment (MAI: the cumulative biomass carbon up to a certain age divided by that age) and the Current Annual Increment (CAI: the growth observed in a stand in a specific one year period) were found to be equal at the age of 37 after the die-back period (Figure 5.2). Therefore the maximum sustained yield was obtained at age 36 after the die-back period in undisturbed natural forests. This result indicates that, if the aim of forest management is to maximise economic returns from wood production, rotation age should be at age 36 because growth rates will gradually reduce and be less beneficial after 36 years of age. However, in the case of carbon sequestration, old age forests can make a positive contribution in terms of net CO_2 flux. Under the likely REDD+ incentive mechanism, old age forests will also deliver benefits therefore it is expected that forests greater than optimal rotation age will also be conserved.

Figure 5.1 Cumulative biomass carbon in undisturbed *S. robusta* forests **(***adopted from Rautienen 1995)*

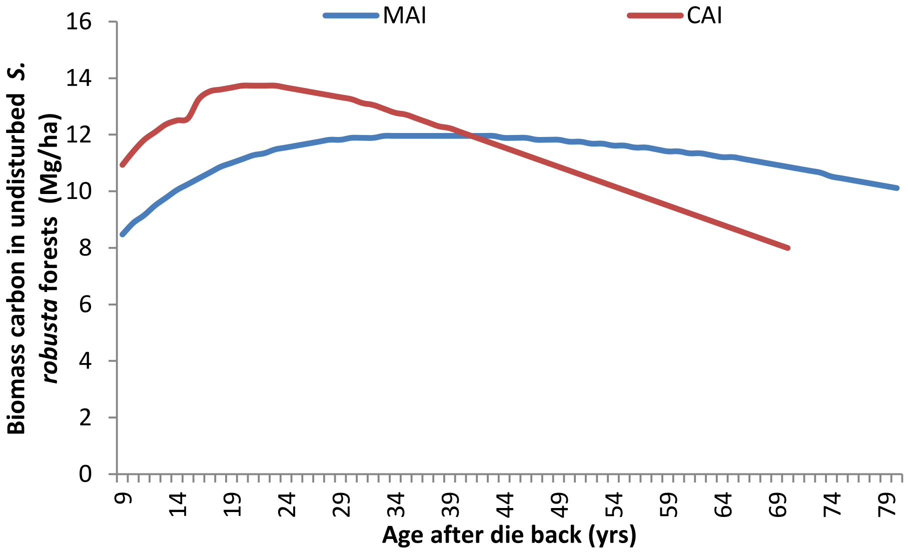


Figure 5.2 Mean Annual Incremenet (MAI) and Current Annual Increment (CAI) in undisturbed *S. robusta* forests *(adopted from Rautienen 1995)*

5.2.2. Biomass carbon growth in CFs

Best fit growth curve for CFs: Coefficients of determination (R^2) calculated for dense *S. robusta* forests were 0.84 using the Richards, Gompertz, Weibull and Morgen-Mercer-Flodin (MMF) models and 0.83 using the logistic and Ratkowsky models. Although four models gave similar R^2 values, the deviation of parameter value was comparatively less (i.e. less range gaps in 95% confidence) in the Gompertz model as was the number of parameters (i.e. three) (Table 5.1 and 5.2). Therefore the best fitted curve explaining biomass growth in dense *S. robusta* forests was given by the Gompertz model with parameters: relative maximum change (a) = 215.36; initial value of the parameter (b) =1.21; and growth rate parameter (c) = 0.06 (Table 5.1). Similarly, for sparse forests, R^2 values for all models were similar but the Gompertz model again used fewer parameters used and was selected as the best to estimate the biomass carbon growth in sparse forests. The parameters estimated and used for sparse forests were a=172.82, b=1.45 and c=0.06 (Table 5.2).

Table 5.1 Dynamic models of relative total biomass accumulation in dense *S. robusta* forests

Models	Fitted equations	Parameters								R^2
		a		**b**		**c**		**d**		
		Value	**Range (95% confidence)**	**Value**	**Range (95% confidence)**	**Value**	**Range (95% confidence)**	**Value**	**Range (95% confidence)**	
Richards	Y=a/(1+exp(b-c*x))^1/d	215.34	193.21 to 237.48	-5.29	-874.63 to 864.04	0.06	0.02 to 0.10	0.001	-1.29 to 1.30	0.84
Logistic	Y=a/(1+b*exp(-c*x))	207.05	196.41 to 217.70	9.69	6.18 to 13.20	0.09	0.07 to 0.10			0.83
Gompertz	Y=a*exp(-exp(b-c*x))	215.36	201.33 to 229.39	1.211	0.97 to 1.45	0.06	0.05 to 0.07			0.84
Weibull	Y=a-b*exp(-c*x^d)	223.32	188.37 to 258.28	241.04	153.39 to 328.69	0.01	-0.01 to 0.04	1.29	0.65 to 1.94	0.84
MMF	y=(a*b+c*x^d)/(b+x^d)	-0.11	-46.96 to 46.74	518.72	-1138.70 to 2176.13	249.47	193.64 to 305.29	1.85	0.88 to 2.82	0.84
Ratkowsky	y=a/(1+exp(b-c*x))	207.06	196.41 to 217.70	2.27	1.91 to 2.63	0.09	0.07 to 0.11			0.83

Note: Gompertz model is found better as it has only three parameter and high R^2

Table 5.2 Dynamic models of relative total biomass accumulation in sparse *S. robusta* forests

Models	Fitted equations	Parameters								R^2
		a		**b**		**c**		**d**		
		Value	**Range (95% confidence)**	**Value**	**Range (95% confidence)**	**Value**	**Range (95% confidence)**	**Value**	**Range (95% confidence)**	
Richards	Y=a/(1+exp(b-c*x))^1/d	171.27	117.64 to 224.91	-1.13	-34.06 to 31.80	0.07	-0.02 to 0.16	0.07	-2.06 to 2.20	0.81
Logistic	Y=a/(1+b*exp(-c*x))	158.85	134.83 to 182.87	17.23	1.09 to 33.37	0.11	0.06 to 0.15			0.81
Gompertz	Y=a*exp(-exp(b-c*x))	172.82	136.74 to 208.90	1.43	0.88 to 1.97	0.06	0.03 to 0.09			0.81
Weibull	Y=a-b*exp(-c*x^d)	167.85	121.20 to 214.49	165.12	93.69 to 236.56	0.002	-0.01 to 0.01	1.83	0.61 to 3.06	0.81
MMF	y=(a*b+c*x^d)/(b+x^d)	8.99	21.74 to 39.72	5206.58	26818.59 to 37231.75	186.22	111.90 to 260.54	2.50	0.55 to 4.46	0.81
Ratkowsky	y=a/(1+exp(b-c*x))	158.85	134.82 to 182.87	2.85	1.91 to 3.78	0.11	0.06 to 0.15			0.81

Note: Gompertz model is found better as it has only three parameter, high R^2 and less ranges in parameter

Biomass carbon in CFs: Using the Gompterz model and estimated parameter values, growth trends of biomass carbon in dense and sparse canopy in dominant *S. robusta* CFs was projected and curves plotted. Both dense and sparse canopy forests show similar trends i.e. high increment at early ages and less in older age stands (Figure 5.3 and 5.4). In CFs, the estimated carbon quantity at age 9 in dense canopy forests was 31.05 Mg/ha while it was 16.93 Mg/ha in sparse forests (i.e. equates to a 14.12 Mg/ha gap). The carbon stock increased to 209.94 Mg/ha in dense and 169.13 Mg/ha in sparse canopy types by age 80 (i.e. a 40.81 Mg/ha gap). Comparing dense and sparse canopy forests, higher gaps were indicated in old aged forest stands than in young stands.

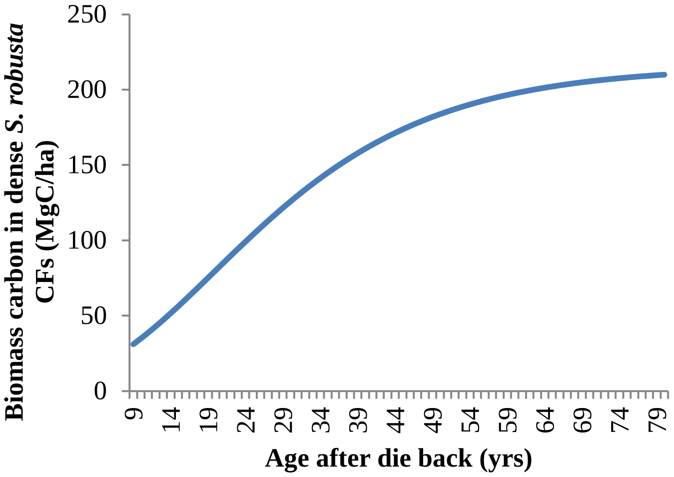


Figure 5.3 Cumulative biomass carbon in dense *S. robusta* dominated CFs

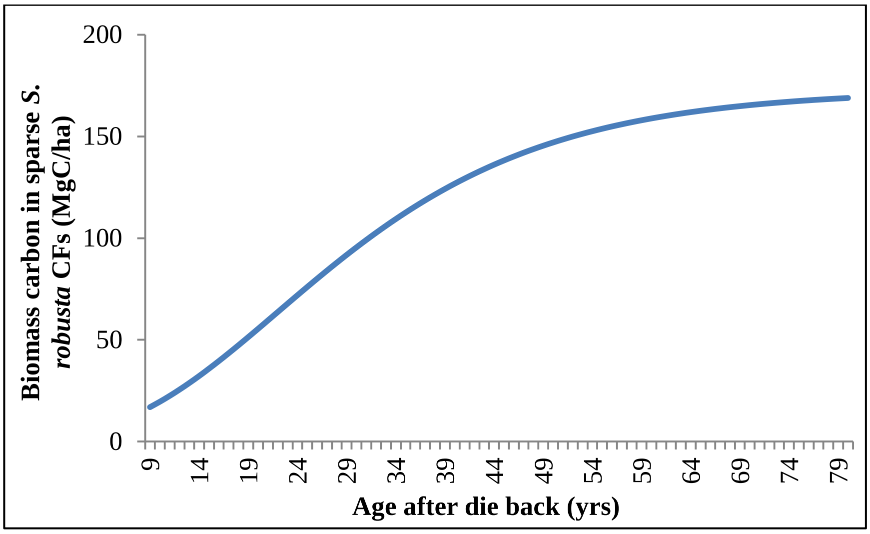


Figure 5.4 Cumulative biomass carbon in sparse *S. robusta* dominated CFs

MAI and CAI curves in dense and sparse canopy forests with *S. robusta* forests were found to differ in CF (Figure 5.5 and 5.6). Biological rotation in CFs currently occurs earlier in dense forests than sparse forests. The CAI and MAI curves intersect at age

30 in dense forest compared to 34 years in sparse forests, after the die-back period, which indicates that increasing the rotation of silvicultural operations is a possibility in dense forests.

While comparing meeting points of MAI and CAI curves for undisturbed forests (40 years, carbon yield 12.09MgC/ha) (Figure 5.2) and dense forests (29 years, carbon yield 4.20 MgC/ha) (Figure 5.5), there were huge differences in meeting point (year) and carbon yields. They are expected as dense forests have over ≥70 % crown cover and have higher number of smaller trees whereas undisturbed forests may have higher number of larger trees.

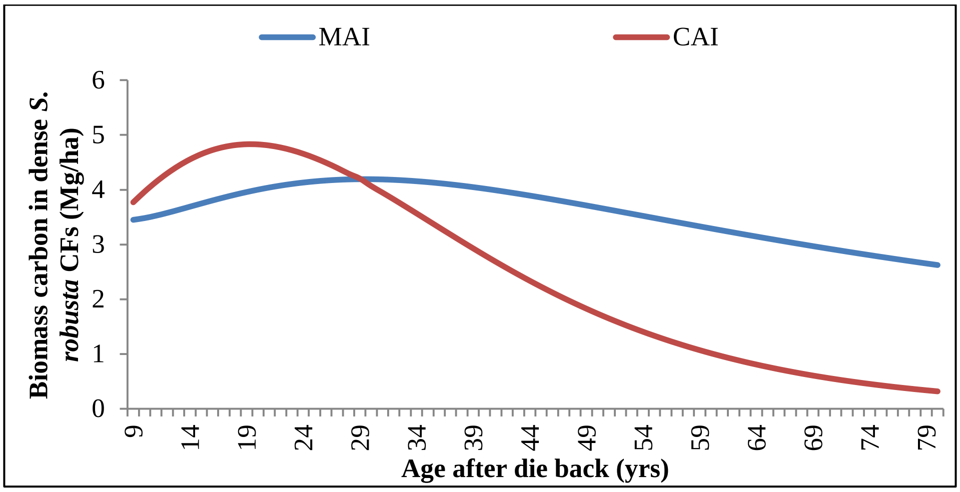


Figure 5.5 Mean Annual Increment (MAI) and Current Annual Increment (CAI) in dense *S. robusta* dominated CF

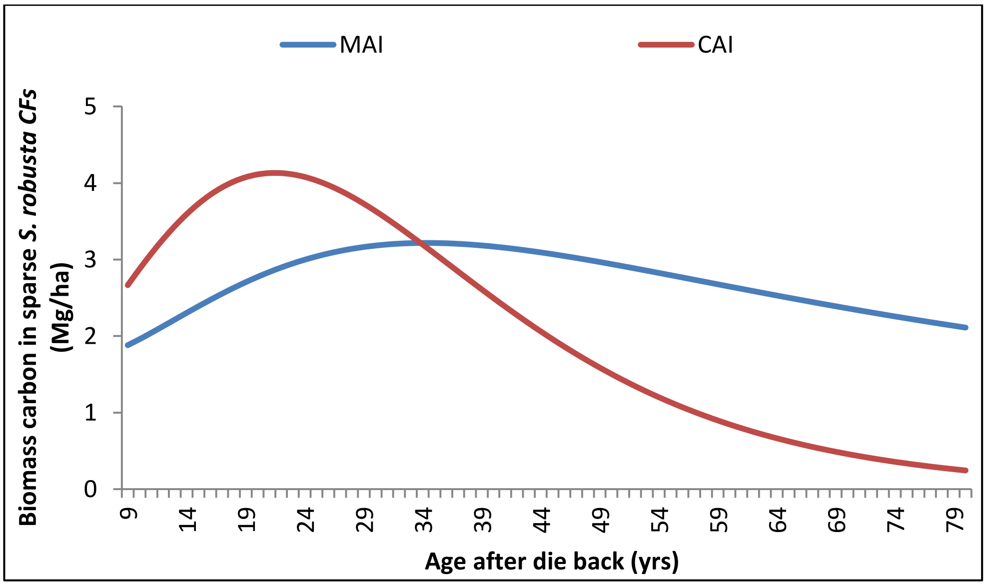


Figure 5.6 Mean Annual Incremenet (MAI) and Current Annual Increment (CAI) in sparse *S. robusta* dominated CF

5.2.3. Carbon growth in undisturbed forests, dense CFs and sparse CFs

There is a remarkable gap in cumulative biomass carbon between dense and sparse canopy CFs within undisturbed uniform (i.e. same age) forests. In Figure 5.7, the area of curve AOF is the theoretical maximum potential carbon stock and the area of BoF is the maximum potential gain in dense CFs. Similarly, the area of EOF is the potential gap between sparse and dense CFs and the combined areas of EOF and BOF is the maximum growth potential of CFs to attain the theoretical maximum (Figure 5.7). The gap between undisturbed forest and CFs was less at early stages and higher in older aged forests. As stated, a possible reason behind this increased gap in later aged stands could be the harvesting practice of CFs where communities might be harvesting larger trees rather than those that are smaller. Most of the CFs were highly degraded at the time of handover and therefore site quality might not be favourable for higher growth rates of early age forests in sparse forests. Both smaller and larger aged trees were fewer in number in CFs than its technical potential.

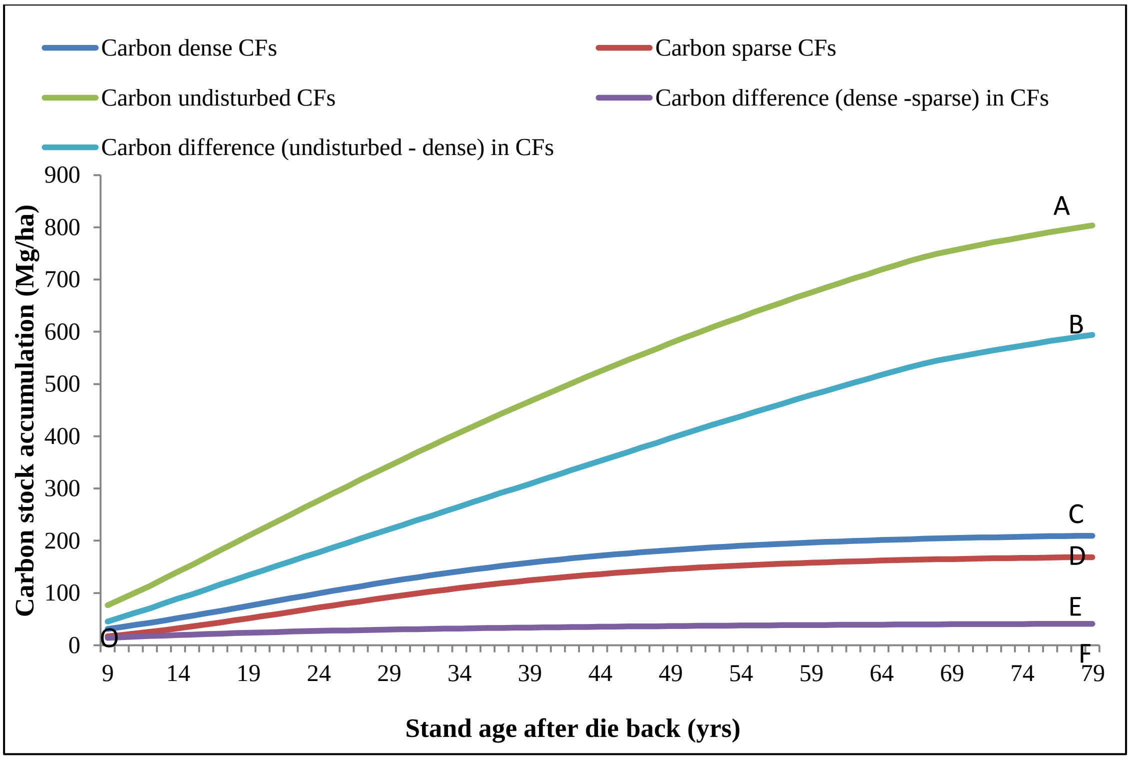


Figure 5.7 Cumulative biomass carbon in undistubed natural forests with uniform age; dense and sparse canopy CFs with average age of dominanat trees in *S. robusta* forests

Results from CurveExpert analysis indicated that the area under the curves was larger in undisturbed forests (i.e. O1O2CB or *o1o2cb* = 34708.07 followed by dense (i.e. O*2O3AB* = 10651.03) and sparse forests (i.e. *o2o3ab* = 8304.57) (Figure 5.8 A &B). These differences show that area of lines showing by undisturbed forests have 2.26 times higher than dense canopy forests and 3.18 times higher than sparse canopy forests, further explaining the gaps.

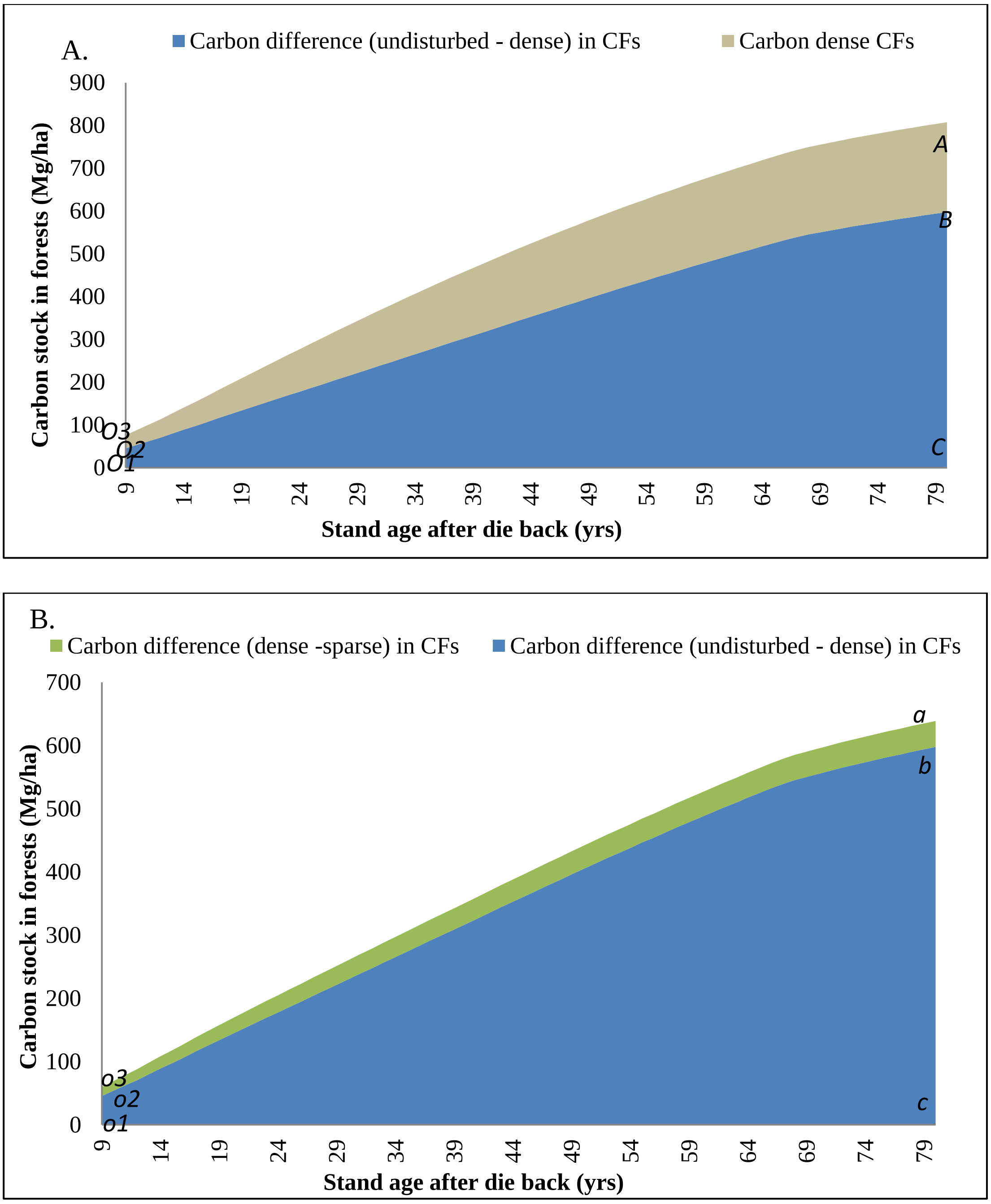


Figure 5.8 Area under curves showing cumulative biomass carbon growth in undistubed natural forests(34,708.07); (A) dense CFs (10,651.03); (B) sparse CFs (8,304.57) in *S. robusta* forests

5.3. Biomass carbon growth in other vegetation types

The highest possible biomass carbon in CFs has been estimated based on the 90th percentile value in plots while the lowest has been estimated in 10th percentile value in plots. The differences between those two extreme values indicate that there is potential for CFs to increase biomass carbon. Among four different forest vegetation types, the highest gap between these two limits were found in dense mixed broadleaf forests followed by dense *Rhododendron-Quercus* forests and the lowest difference was apparent in sparse *Schima-Castanopsis* forests (Table 5.3).

Table 5.3 Gaps between 10th percentile and 90th percentile value of carbon stock in both dense and sparse canopy types CFs by vegetation

Forest types	Total plots	10th percentile value	90th percentile value	Difference
Sparse mixed broadleaf	10	7.59	133.83	126.24
Dense mixed broadleaf	53	26.88	224.04	197.16
Sparse *Schima-Castanopsis*	18	8.65	89.48	80.83
Dense *Schima-Castanopsis*	98	28.91	177.49	148.58
Sparse *Pine*	12	13.68	102.35	88.67
Dense *pine*	30	36.35	175.87	139.52
Sparse *Rhododendron-Quercus*	13	3.56	139.67	136.11
Dense *Rhododendron-Quercus*	60	39.46	208.43	168.97

5.4. Conclusion

Based on the results presented in this chapter, it is apparent that there are possibilities to increase biomass carbon in both dense and sparse canopy type CFs. Increment potential is higher in sparse forests than dense. Comparison with theoretical maximum growth patterns indicates that differences between sparse and dense CFs are higher in old age forests than early stage forests. This shows that CFs may be harvesting or losing old age trees from their stands. However if REDD+ activities are designed to ensure benefits to CFUGs, they may reduce the harvesting of trees and help to reduce the gap between current and maximum potential growth of forests.

To reduce these gaps and increase the biomass carbon of CFs, CFUGs need to develop plans that consider the factors affecting carbon stock increments in forests. The possible factors affecting biomass carbon in CFs are discussed in the next chapter.

CHAPTER SIX

CHANGED BEHAVIOUR OF THE COMMUNITIES AND FACTORS AFFECTING CARBON STOCK AND CARBON STOCK CHANGES IN THE REDD+ CFs

6.1. Introduction

The previous chapter presented the potential carbon growth in undisturbed forests and CFs by canopy cover and vegetation type. This chapter describes changed practices of local communities for the REDD+ project and factors affecting carbon stock in CFs. This chapter also presents evidence of changed community practices in forests, different possible factors and possible relationships with carbon stock and change in carbon stock in the respective experimental plots in CFs.

This chapter is divided into eight sections. The next section gives evidence of the relationship between changes in community behaviour and biomass reduction in the forests. In the third, fourth, fifth, sixth and seventh sections biomass quantity in year 2010 and change in carbon stock between 2010 and 2013 is presented in relation to different elevation forests, different proximity from road head, different proximity from settlement, different average age of the dominant trees in CFs and various socio-economic aspects of CFs (including per capita forests available, household level landholding, size of household level livestock (Livestock Unit), biogas using households in CFs, petroleum energy using households in CFs, biomass extraction, grazing, caste heterogeneity (index) in CFs, quantity of grass collection, fodder collection, litter collection) respectively. The final section concludes the chapter.

6.2. Evidence of changed behaviour of communities related to biomass reduction in the forests

Evidences of biomass reducing incidences (forest fire, livestock grazing, fodder collection, fuel wood collection, and timber collection) recorded during annual carbon pool measurement (between 2010 and 2013) in CFs showed decreasing trends in later years of the REDD+ project (Figure 6.1, 6.2, 6.3, 6.4 & 6.5). The decreasing rates in the frequencies of these incidences differed by vegetation types and by year in which measurement was taken. These evidences of incidences are presented individually in the sub-sections below.

Forest fire

Comparatively forest fire incidences were observed in higher proportion of plots in dense canopy of forests at the reference year 2010 except R*hododendron-Quercus* forests. The incidence of fire fell over the following years and was least in the year 2013. Communities contributed to controlling the incidence of forest fire in dense canopy mixed broadleaf forests and were able to reduce fire frequency from nearly 40% of plots in the year 2010 to 10% in the year 2013 (Figure 6.1). There were still high forest fire incidences in sparse canopy *Schima-Castanopsis* and *Pine* forests which may require additional fire control efforts by these communities.

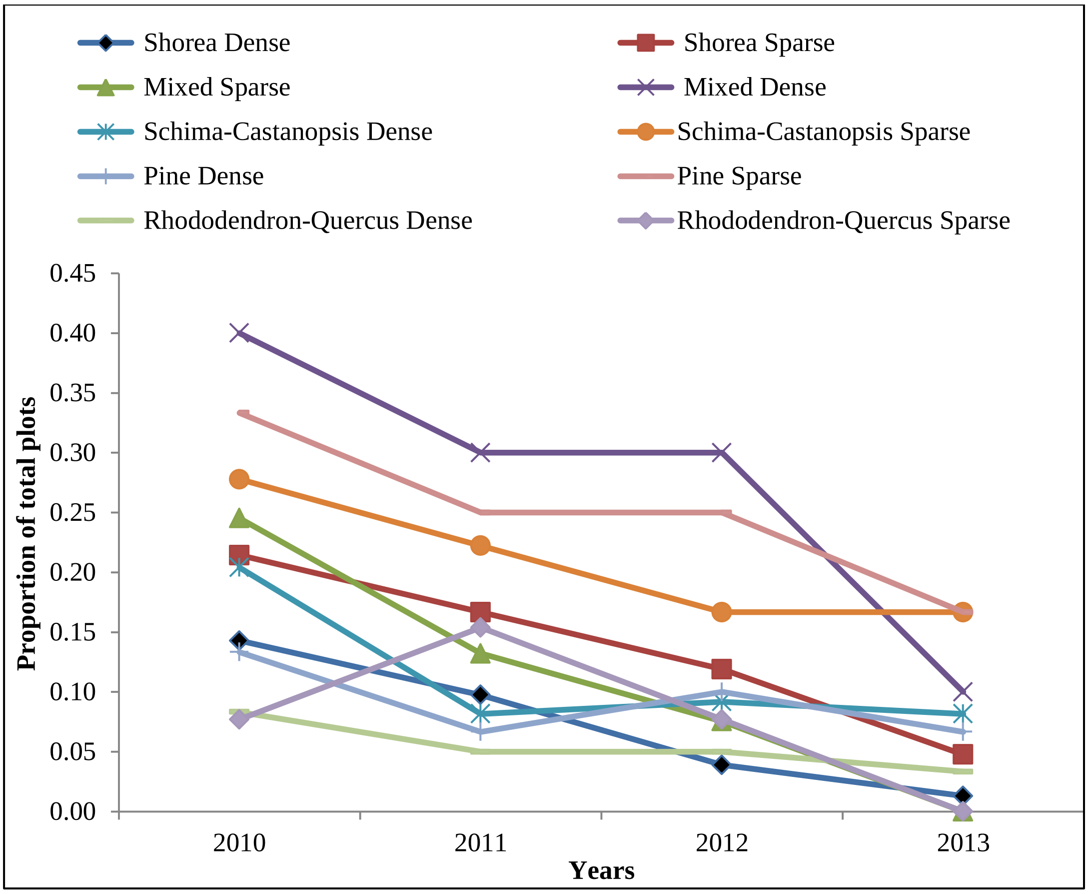


Figure 6.1 Observed forest fire incidence by proportion of total plots in different vegetation and canopy cover types

Grazing

Grazing incidence was highest in both dense and sparse canopy *Rhododendron-Quercus* forests followed by sparse canopy *S. robusta* forests and lowest in dense canopy *Shorea* forests and dense canopy *Schima-Castanopsis* forests. Grazing in all forests gradually reduced in the later years of the study, indicating that local communities were controlling livestock grazing after the REDD+ project activities commenced. A higher level of livestock grazing (in more than 30% of plots) was found in sparse canopy of *Rhododendron-Quercus* forests in 2013 which means that communities were still sending their livestock into CFs; this practice may need to be controlled to achieve maximise REDD+ carbon benefits (Figure 6.2).

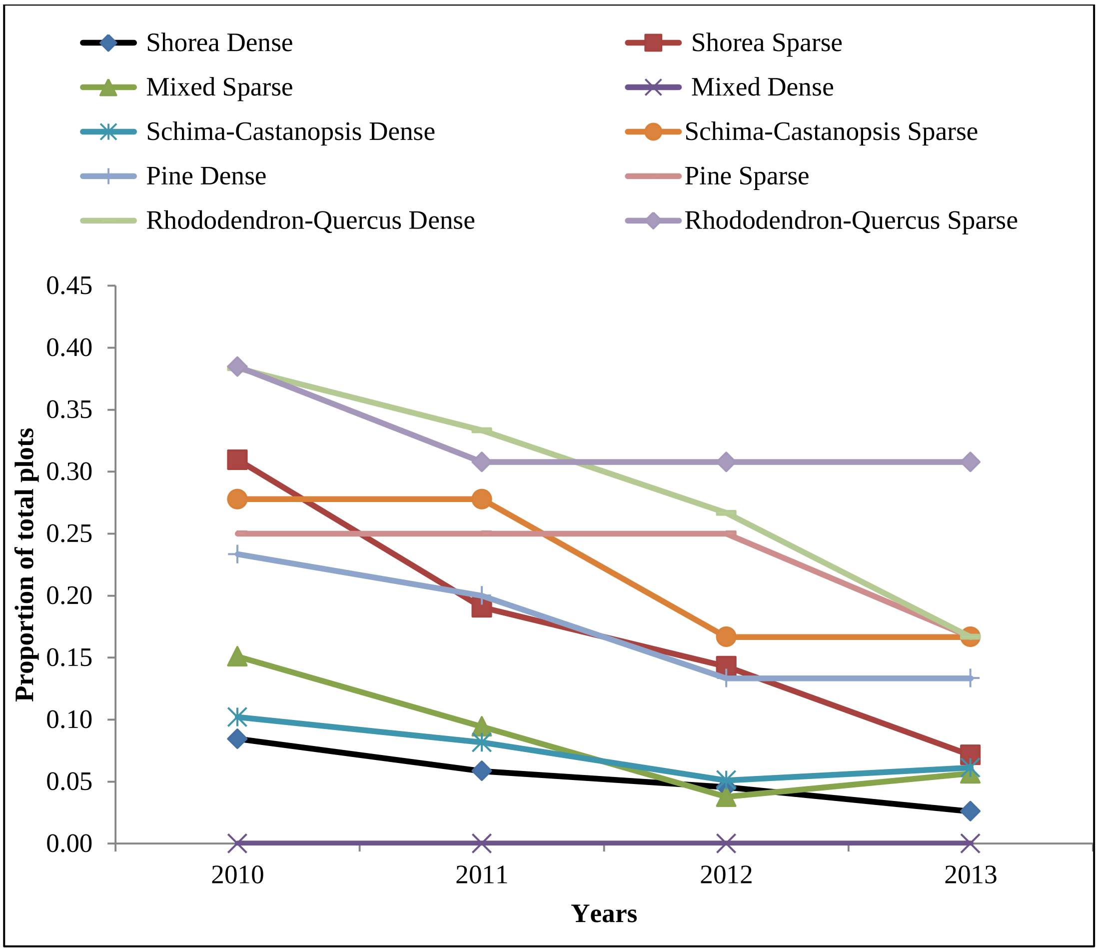


Figure 6.2 Observed livestock grazing incidence by proportion of total plots in different vegetation and canopy cover types

Fodder collection

A higher proportion of plots had fodder collection in both sparse and dense canopy mixed broadleaf forests in 2010 followed by dense canopy *Schima-Castanopsis* forests; this practice was lowest in sparse canopy *Schima-Castanopsis* forests. Fodder collection decreased slightly in the year 2013 in all forests, but the rates of decrease were highest in *Schima-Castanopsis* forests, followed by sparse canopy *S. robusta* forests and lowest in sparse canopy *Pine* forests (Figure 6.3).

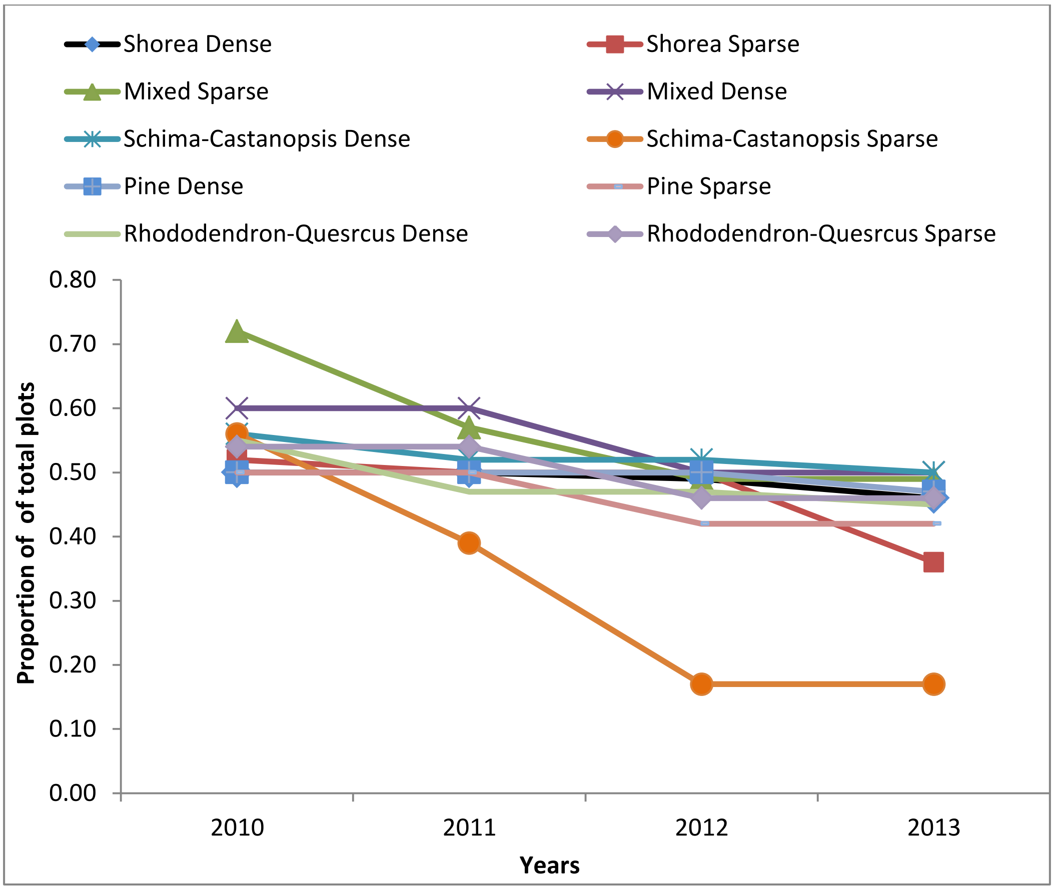


Figure 6.3 Observed fodder collection incidence by proportion of total plots in different vegetation and canopy cover types

Fire wood

A higher proportion of plots in dense canopy *S. robusta* forests had firewood collection incidences followed by dense canopy *Schima-Castanopsis* forests while this was lowest in dense canopy mixed broadleaf, sparse canopy *Pine* and sparse canopy *Schima-Castanopsis* forests. There seems to be a very slight decrease in firewood collection during the REDD+ project, although this trend is not evident in the dense *Rhododendron-Quercus* forests (Figure 6.4).

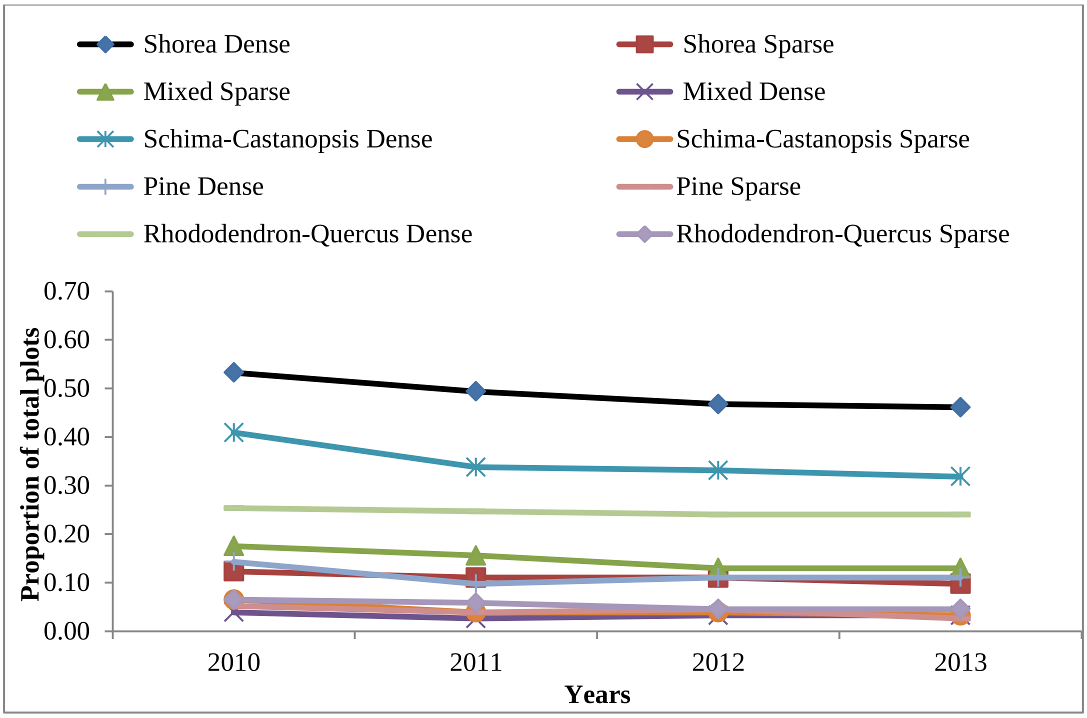


Figure 6.4 Observed firewood collection incidence by proportion of total plots in different vegetation and canopy cover types

Timber

A lower proportion of plots had timber harvesting incidences in all vegetation types (i.e. less than 10% of plots) (Figure 6.5). The study results showed a reduction in timber harvesting in plots (with proportion of timber harvesting plots least in the year 2013 in all vegetation types) while there were no regular reduction trends. In the reference year 2010, a highest proportion of timber harvesting plots was found in dense canopy *S. robusta* forests followed by dense canopy *Schima- Castanopsis* forests and lowest in dense canopy mixed broadleaf forests.

According to local communities, there were no regular tree harvesting practices in their CFs because they only decide and allow tree harvesting for timber if someone from one of their member groups demands timber to build or renovate their house. But that type of timber demand does not come every year and timber harvesting could be seen only when and where communities had demand and decided to cut trees (Annex H).

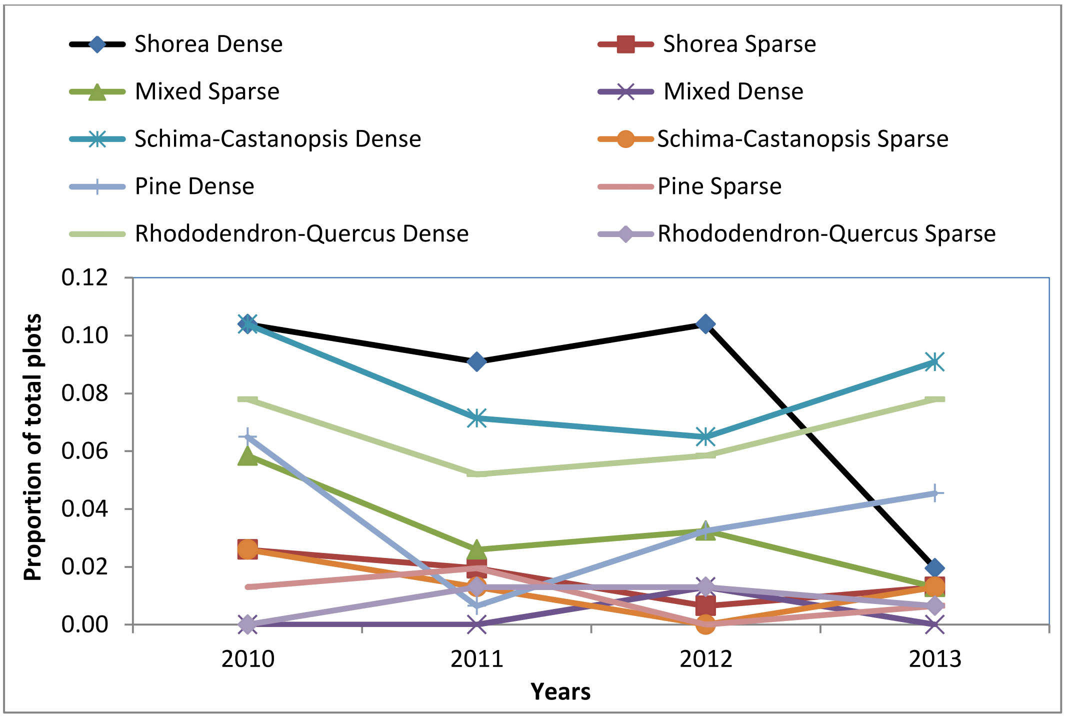


Figure 6.5 Observed timber collection incidences by proportion of total plots in different vegetation and canopy cover types

6.3. Changed practices of CFUGs for the REDD+ project

With facilitation of the REDD+ project, CFUGs have changed some of their existing behaviours, mainly: decision making processes; forest management practices; forest product collection; and forest biomass reduction activities, in order to increase biomass carbon in forests (Table 6.1).

According to Focus Group Discussions (FGDs), most CFUGs make decisions through participatory processes by organising meetings of the executive committee and General Assembly (GA) of CFUG members. The numbers of both the meeting and GA are increased and the agenda of both meeting and GA have been expanded by adding awareness raising and processes for the REDD+ mechanism and activities. The level of practice change was found to be greater in *S. robusta*, mixed broadleaf and *Rhododendron-Quercus* forests than before REDD+ project. All CFUGs have increased their carbon increment goals following the REDD+ project intervention. In order to achieve these goals, the project provided technical guidance about forest management activities and material support about planting to CFUGs. Now, most CFUGs operate regular silvicultural activities (mainly removing dead, dying, diseased and malformed trees from forests) except in *Rhododendron-Quercus* forests and do plantation activities in all Community Forests (CFs) except *S. robusta* forests. Similarly, communities have reduced the quantity of timber harvesting from CFs with the highest reduction in *S. robusta*, followed by the mixed broadleaf and *Schima-Castanopsis* forests. Most CFs have made provisions to collect dry and fallen branches and trees for fuel wood on certain days of each month except in *Rhododendron-Quercus* forests. Fodder collections are open during certain months in some lower altitude CFs and litter collections are mainly open for *Schima-Castanopsis* and *Rhododendron-Quercus* forests. There was no reduction in the quantity of tradable NTFPs harvested in CFs. Majority CFs conduct activities to control possible damage from forest fires, illegal harvesting and grazing. More specifically, care was increased to control forest fire in *S. robusta*, mixed broadleaf forests and *Pine* forests and illegal harvesting in *S. robusta* and mixed broadleaf forests. In order to reduce the dependency on forest products in CFs, communities have reduced numbers of unproductive livestock, increased plantations on private unproductive agricultural lands and the use of alternative energy (Improved Cooking Stove-ICS, and biogas plants).

Table 6.1 Summary of the changed practices in CFs for REDD+ in the study areas

Activities	**Changes (common for all CFs)**	**Specific by species dominated CFs**
1. Decision making process		
Executive committee meeting	- Executive committees are more inclusive, representing all castes and economic groups - Numbers of meeting are increased - Agenda of meeting are expanded to include REDD + activities and plan - Number of participants in meeting is increased - Now members of the committee are more motivated to contribute to forestry activities	No more differences between vegetation types however small forests and *Schima-Castanopsis* and *Pine* forests have no much change because they are less heterogeneous (community) and were doing well even before the REDD+ project
General assembly (GA)	- Increased numbers - Increased number of participants - Agenda of GA has been expanded to awareness, planning and capacity building for REDD+ activities and benefits sharing	No more differences between vegetation types
2. **Forest management practice**		
Aim	- Expanded from improvement of forests and sustainable use of forest products to maintaining ecosystem services including forest carbon stocks	After the REDD+ concept evolved in the study areas, all CFs aimed to go for increasing forest carbon stock
Silviculture operation	- Silviculture operations are being operated annually on a more regular basis in most of CFs - Clearing and thinning is done to create a more conducive environment to grow trees	More regular in CFs with *S. robusta* mix broadleaf, *Schima-Castanopsis* vegetation
Plantation	- Plantation activities in some of the CFs (both in forests and uncultivated private land) are increased - Project supported to give technical knowledge, seedling for plantation - All labour for plantation activities was done by users	Comparatively less in *S. robusta* forests
3. Forest product		

collection from CFs		
Timber	- Quantities of timber harvesting is less than before - Timber is distributed only to needy user members - Quantities of timber sold is decreasing in most of CFs	- Quantity of harvests has been reduced particularly in Terai (*S. robusta*) and mid-altitude (*Pine* and *Schima-Castanopsis*) (about 70%) compared to higher altitude *Rhododendron-Quercus* (about 40%) CFs
Fuel wood	- Mostly allow collection of dry and fallen wood - Dry and fallen branches/ trees are collected on certain days in a month - Green wood obtained from silvicultural operations are distributed for fuel wood - Collection of bent and forked green trees for fuel wood is permitted during silviculture operation	- Open only for 1-2 days in each month in *S.robusta, Pine* and *Schima-Castanopsis* forests whereas open for all days in *Rhododendron-Quercus* forests to collect dead/dying and fallen branches for fuel wood Green trees in *S. robusta* forests are not allowed to be harvested
Fodder/grass	- Fodder and grass collection is made in a systematic way for REDD+ - Green seedlings and poles are not allowed to be cut in forests for fodder and grass supply - Non woody grasses are allowed to be collected without damaging regeneration	- Open to cut green ground grasses for the whole year in higher altitude *Rhododendron-Quercus* forests whereas it is open for certain months in some CFs at lower altitudes
Litter	- Litter collection is not controlled but the quantity of collection has been reduced	- Collection is higher in *Schima-Castanopsis* and *Rhododendron-Quercus* forests because the main aim of litter collection is to make manure by decomposing the leaves but *Pine* needles and S*horea* leaves take time to decompose and are not preferred by communities.
NTFPs	- Income from NTFPs has been increased with access to market information - Lokta (*Daphne bholua*), Wintergreen (*Gaultheria fragrantissima*) and Chiuri *(Bassia butyracea)* are major marketable NTFPs plants of the study areas - Lokta and Wintergreen are not large wood trees and collection of them in a sustainable way may not affect to the overall biomass carbon in the forests. Chiuri is a tree but people collect fruits for butter that does not affect the carbon quantity - Collection of NTFPs which are used for food, vegetable or medicine at the local	- Middle and higher latitude forests (mainly *Schima-Castanpsis* and *Pine*) get more income from NTFPs in the study areas

	level and income gained by selling these has not been changed but careful collection has been encouraged	
4. Forest biomass reduction activities		
Forest fire	- Preventive measures (awareness about possible causes and effects of forest fire and preparing firelines to reduce possible damage of forest fire) are carried out between February to March - Users are gathered and worked together to control forest fire if these occur	- Fire risk is higher in lower altitude forests (*S. robusta* and mixed broadleaf) and less in middle altitudes (*Schima-Castanopsis* forests) - Pine forest is more sensitive due to flammable resin and communities are engaged in preventive measures. - Participants get food or small amount of money to attend fire control activities in Terai CFs but these are fully voluntary in other forests.
Illegal harvesting	- Most of the CFs have developed guarding provision to control illegal activities, control forest fire and reduce damages to plantations	- In *S. robusta* forests, lower altitude CFs appoint 1 or 2 persons as guard or watchman for the whole year in most cases - In hill areas, communities guard forests against illegal activities in rotation. They guard forests only for a certain months when there is high potential of illegal activity
Grazing	- Grazing is almost controlled in CFs. Few CFs have some grazing practices at the forest edge (i.e edge between forest and agricultural land and/or nearby settlement)	- In *Rhododendron-Quercus* forests, there are some grazing practices permitted. These are almost controlled in *Schima-Castanopsis*, *Pine* and *Schorea* mixed broadleaf forests.
Encroachment	- Encroachment has been fully controlled in CFs	
5. **Other related activities**		
Livestock	- Communities have reduced unproductive livestock (mainly cows) - Number of goats is increasing in many CFs for income generation	- Not much difference in pattern of CFs by vegetation types
Private plantation	- CFUG members have initiated plantation of fodder and grass on private marginal lands - Project helped deliver seedling and	- More in *Schima-Castanopsis* and *Pine* forests located at middle altitude forests

	technical knowledge about plantation	
Use of alternative energy	- Improved Cooking Stove (ICS), Biogas and LG gas are the main changed alternative energy practices in CFs to reduce household level fuel wood consumption - Project provided partial financial and technical support for the use of ICS and Biogas for households energy	- Higher proportion of households using biogas in lower altitude (*S. robusta* and mixed broadleaf forests); less in middle altitude (*Schima-Castanopsis* and *Pine* forests) than higher altitude (*Rhododendron-Quercus* forests) - Higher proportion of households adopted ICS in higher altitude forests whereas a higher proportion of households adopted Biogas at lower altitudes. This is also due to feasibility from both environmental and economic point of view.

(Source: FGD: 2012)

6.4. Elevation of the forests

A relationship between altitude and average carbon stock (MgC/ha) in the reference year 2010 and the change in carbon stock (MgC/ha) between 2010 and 2013 in plots, by vegetation and canopy types, were analysed and are presented in this section.

Although, the scatter plots of carbon stock and change in carbon stock by altitude variation in all plots of specific vegetation type showed no significant correlation, there were different indicative trends. In *S. robusta* forests, the biomass carbon stock in year 2010 indicated a slightly negative relationship with altitude whereas changes in carbon stock indicated a positive relationship (Figure 6.6). Mixed broadleaf forests seems to have a positive but slight relationship with altitude for both carbon stock in 2010 and change in carbon stock (Figure 6.7). The relationship between altitude and carbon stock in 2010 was slightly negative but positive with carbon stock change in *Schima-Castanopsis* forests (Figure 6.8). The opposite was true in the case of both *Pine* forests and *Rhododendron-Quercus* forests where carbon stocks seemed to be positive with altitude in the year 2010 but carbon stock changes were negative (Figure 6.9; Figure 6.10)

The relationship between altitude and carbon stock in the year 2010 was slightly positive in sparse canopy forests of all vegetation types but the relationship seemed to be negative with changes in carbon stock between 2010 and 2013. This was similar in dense canopy of Pine forests and *Rhododendron-Quercus* forests whereas it was almost opposite in *S. robusta* forests, mixed broadleaf forests and *Schima-Castanopsis* forests (Figure 6.6; 6.7; 6.8; 6.9 and 6.10).

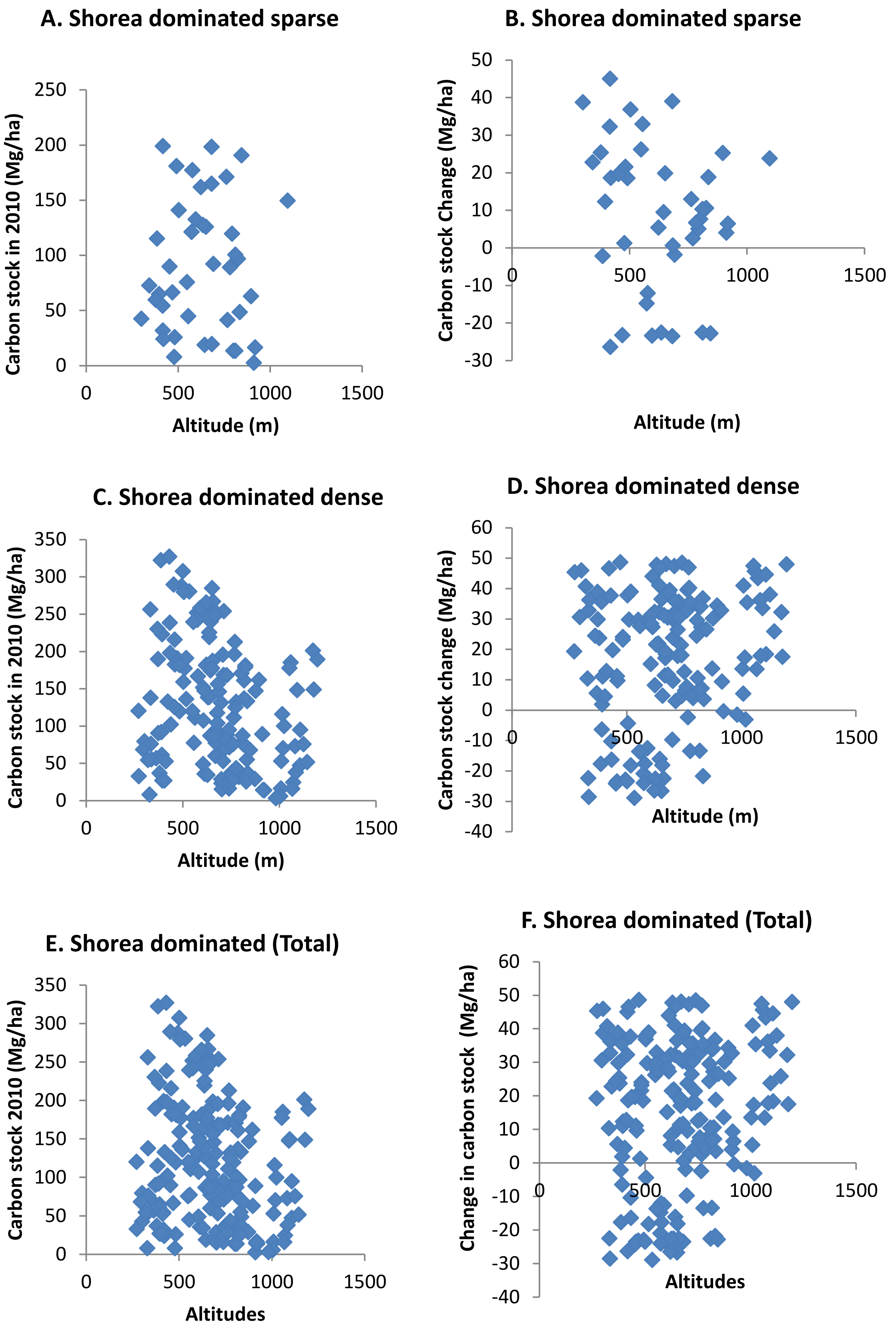


Figure 6.6 Scatter plots showing relationship between carbon stock (average in year 2010 and change between 2010- 2013) in *S. robusta* dominant forests by canopy types

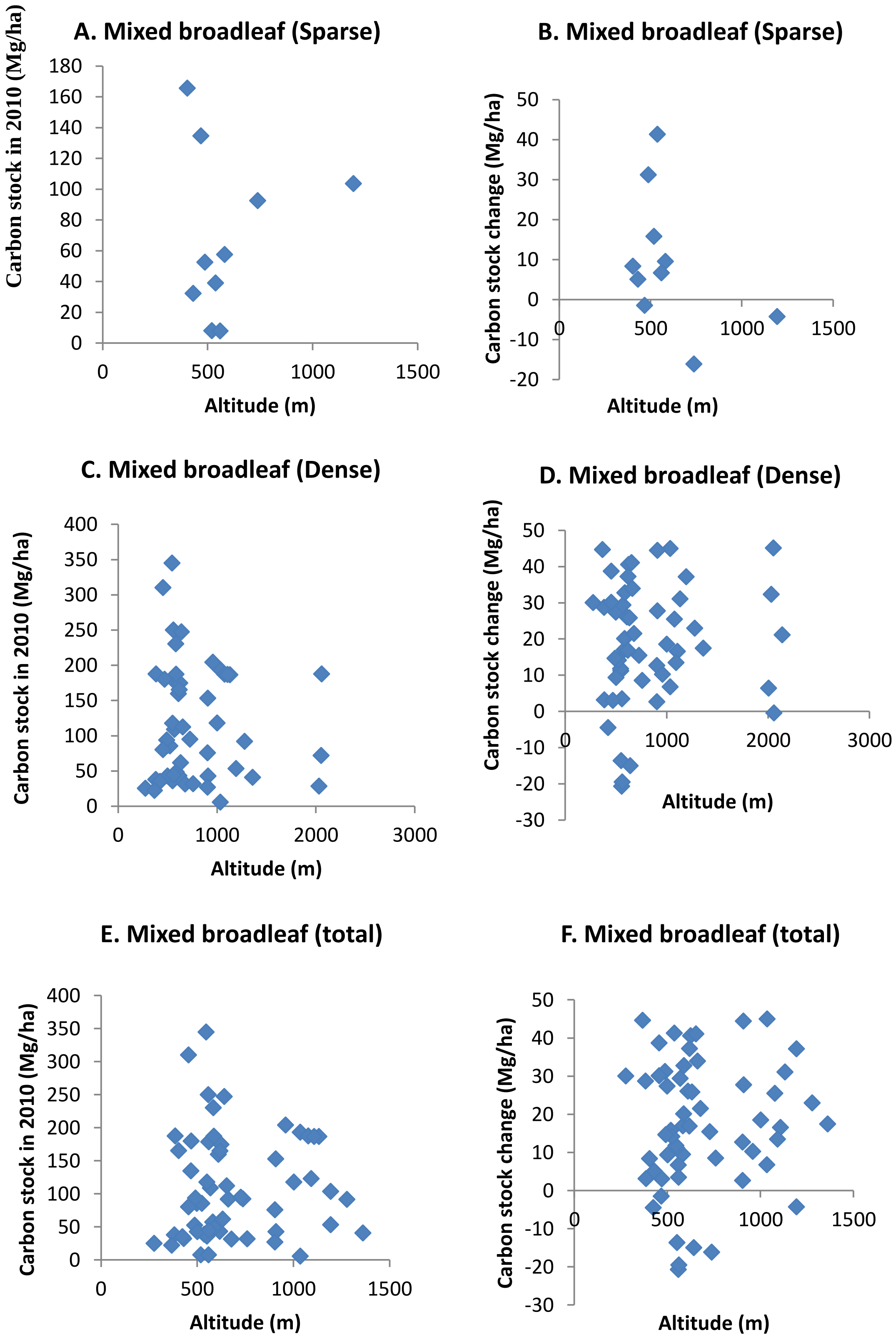
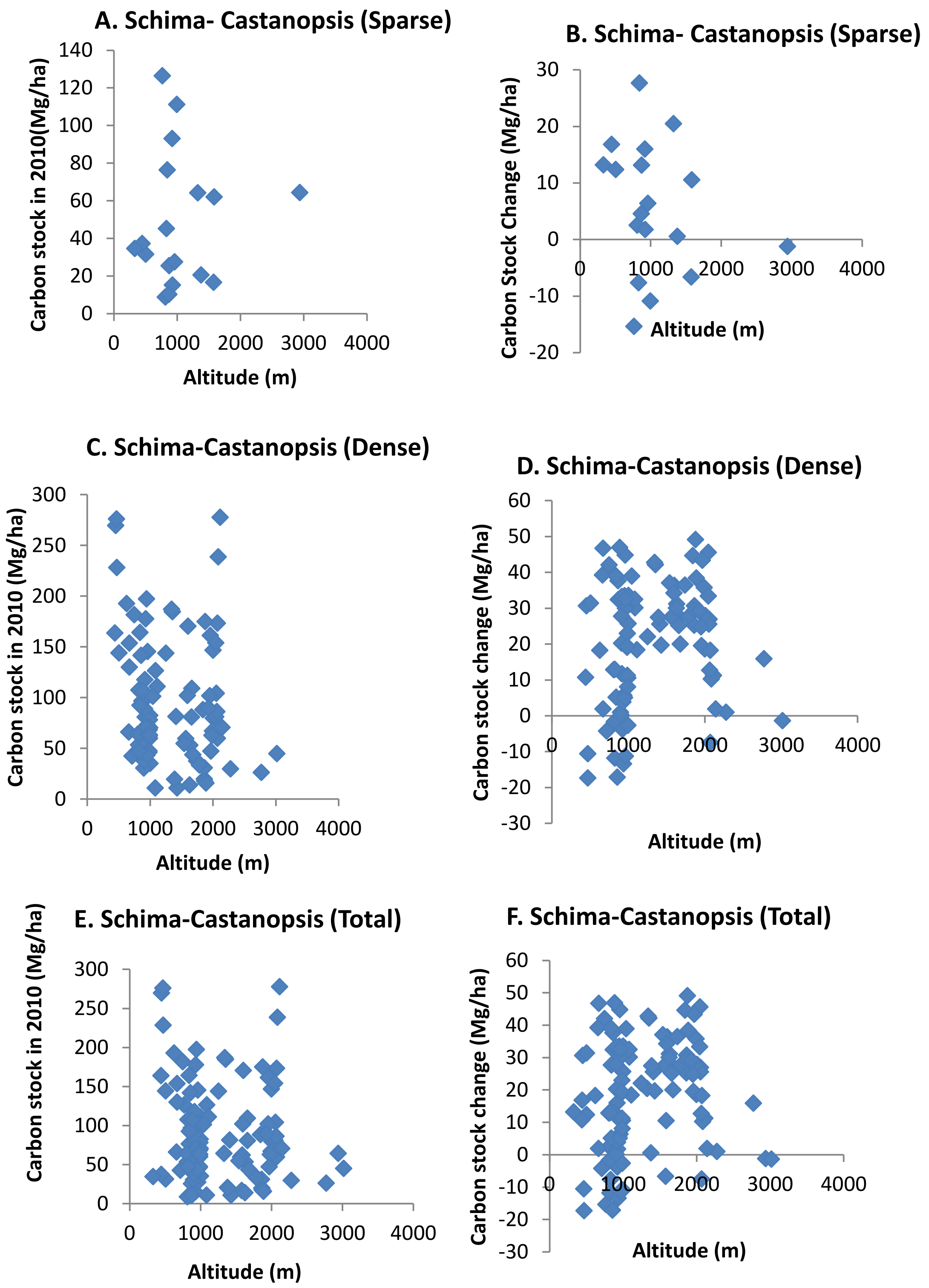


Figure 6.7 Scatter plots showing relationship between carbon stock (in year 2010 and change between 2010 - 2013) in Mixed broadleaf forests by canopy (A-F)



A. Schima- Castanopsis (Sparse)

B. Schima- Castanopsis (Sparse)

C. Schima-Castanopsis (Dense)

D. Schima-Castanopsis (Dense)

E. Schima-Castanopsis (Total)

F. Schima-Castanopsis (Total)

Figure 6.8 Scatter plots showing relationship between carbon stock (in year 2010 and change between 2010-2013) in *Schima-Castanopsis* forests by canopy types (A-F)

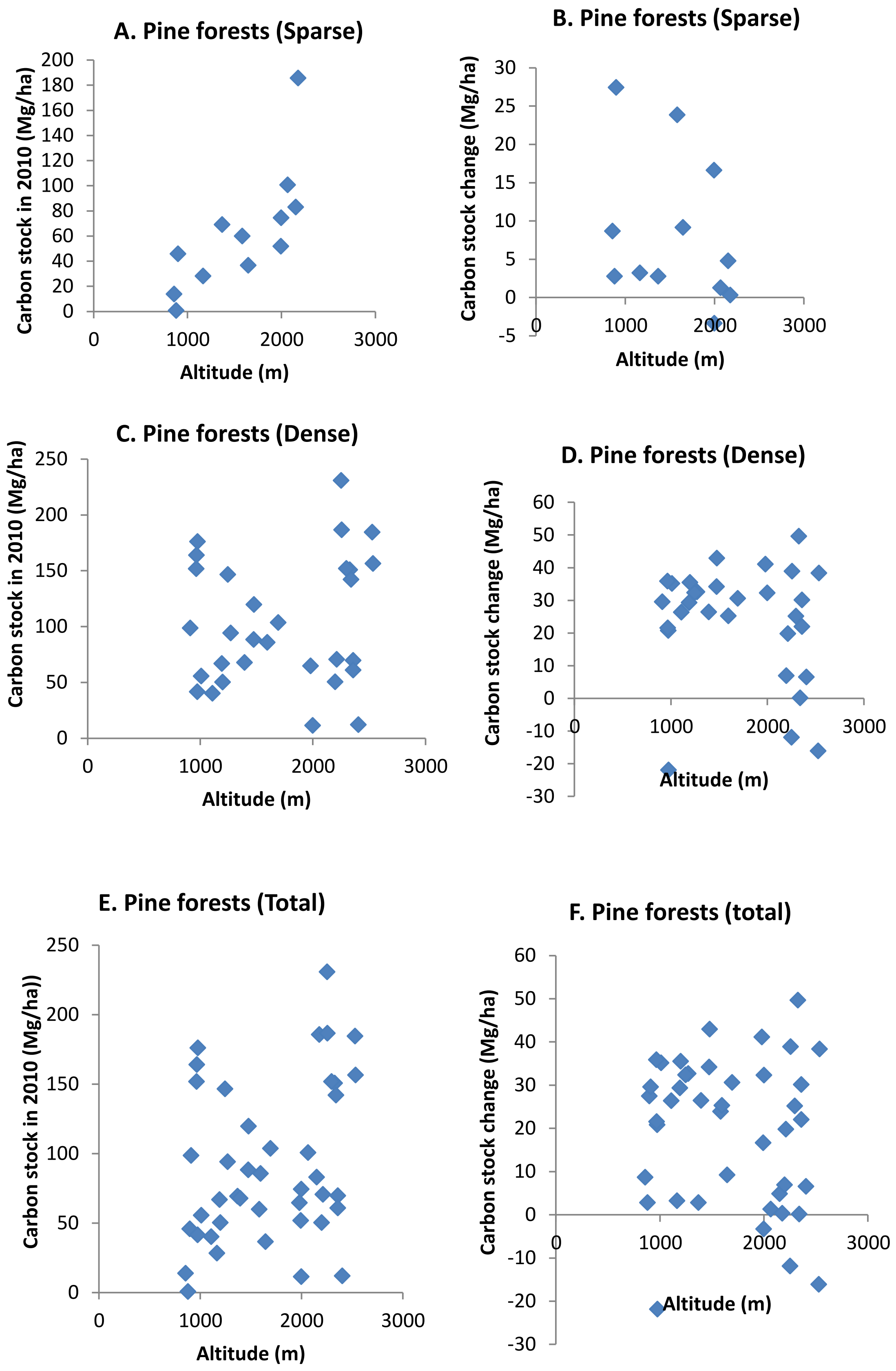


Figure 6.9 Scatter plots showing relationship between carbon stock (average in year 2010 and change between 2010- 2013) in *Pine* forests by canopy types (A-F)

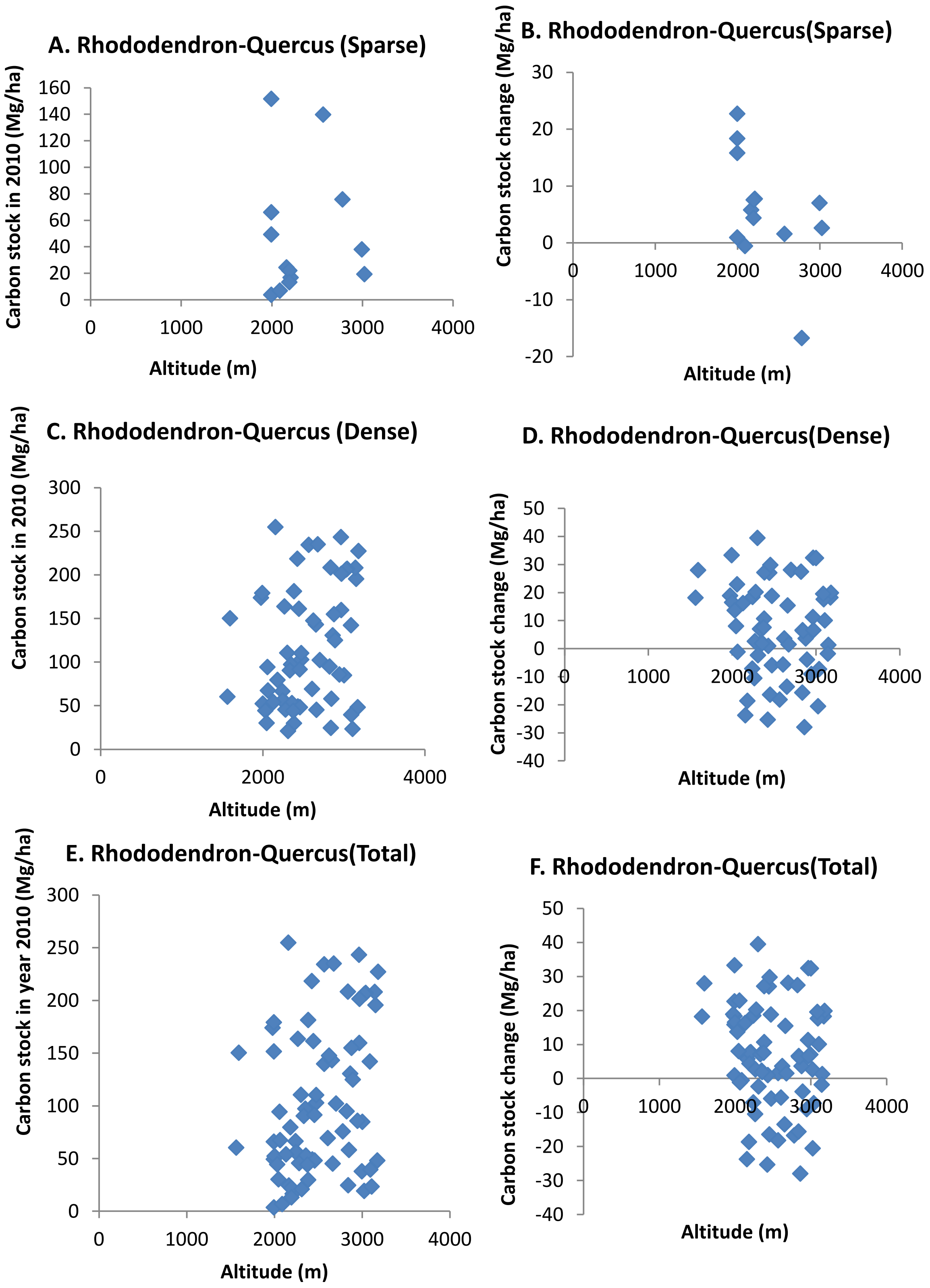


Figure 6.10 Scatter plots showing relationship between carbon stock (average in year 2010 and change in carbon stock between 2010 and 2013) in *Rhododendron-Quercus* forests by canopy types (A-F)

6.5. Proximity of forests from road head

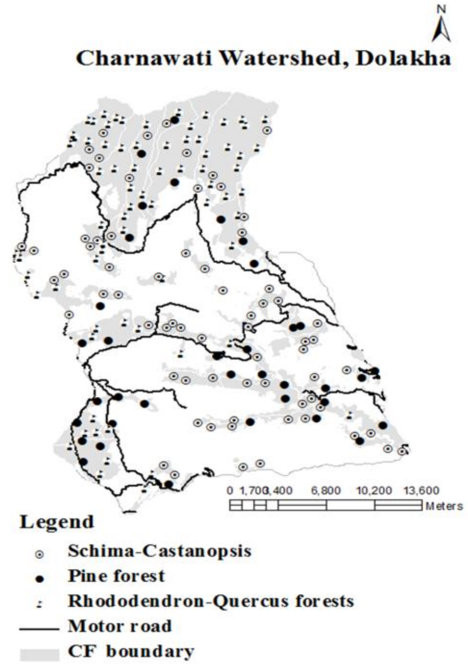
Location of plots (by distance) from nearby road head was found to differ in analyses of satellite imagery and road data (Figure 6.11). The results showed that average carbon stock in plots located further from the road head was higher in the year 2010 (Table 6.2). According to communities, road access had increased the harvesting of timber and firewood especially before community forestry started. This might be a reason for lower carbon stocks near roadheads in all vegetation forests except Pine. Pine forests were mostly plantation forests and plantation activities were greater at locations close to roads.

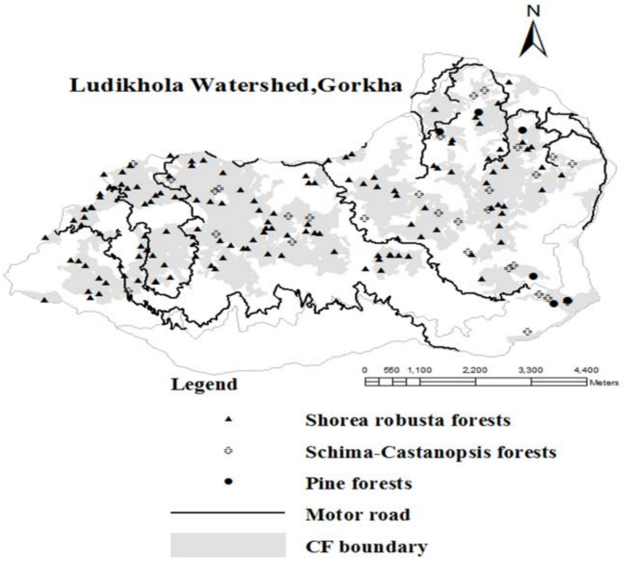
Average changes in carbon stock (between 2010 and 2013) were also found to be higher in area located close to the roadhead in all vegetation types except pine forests (Table 6.2). This shows that where there were higher carbon stocks in plots during the reference year these tended to have lower carbon increments over the study period. This indicates that these communities have conserved forest biomass with the REDD+ activities. However, in some plots, there was higher removal of biomass (higher negative value in the range of carbon stock estimates in plots in Table 6.2) which shows there were some over harvesting or illegal harvesting going on closer to road heads.

Table 6.2 Proximity (Road to plots) and average C-stock (MgC/ha in year 2010) and change in C-stock (between 2010-2013, MgC/ha) in forests analysing 21 plots located at farthest away and 21 at closest from the road head

Vegetation types	**Ave. distance (m)**	**Range (m)**	**C-stock in year 2010 (MgC/ha)**	**Range (MgC/ha)**	**C- change 2010-2013 (MgC/ha)**	**Range (MgC/ha)**
Shorea robsuta forests	40.5	1.5-92.7	108.5	13.3-200.8	**15.8**$^{\#}$	-23.4-47.7
	1310.8	990.6-3892.1	**118.4***	15.0-265.4	14.8	-26.7-43.3
Mixed broadleaf forests	290.4	29.5-493.6	105.3	8.0-345.1	**17.2**$^{\#}$	-4.5-45.2
	2828.9	927.9-4360.0	**127.0***	27.1-310.3	15.8	-20.7-44.5
Schima-Catstanopsis	174.3	28.9-292.6	89.5	10.9-269.7	**20.8**$^{\#}$	-15.4-43.3
	2231.6	1170.0-4541.6	**93.5***	10.8-277.7	17.5	-17.1-39.0
Pine forests	205.2	20.7-384.5	102.9	11.9-230.6	15.3	-21.9-42.9
	971.4	452.6-3094.9	79.9	0.6-186.5	23.6	0.1-49.6
Rhododendron -Quercus	275.2	63.6-554.9	73.4	13.3-174.0	**10.0**$^{\#}$	-18.8-29.8
	2548.5	1747.3-3636.0	**149.9***	23.5-243.2	7.5	-28-33.3

Note: * higher average biomass carbon (above ground and below ground, in 2010) plots located at far from road head, # higher change in biomass carbon (above ground and below ground, between 2010 and 2013) in plots located at close from road head





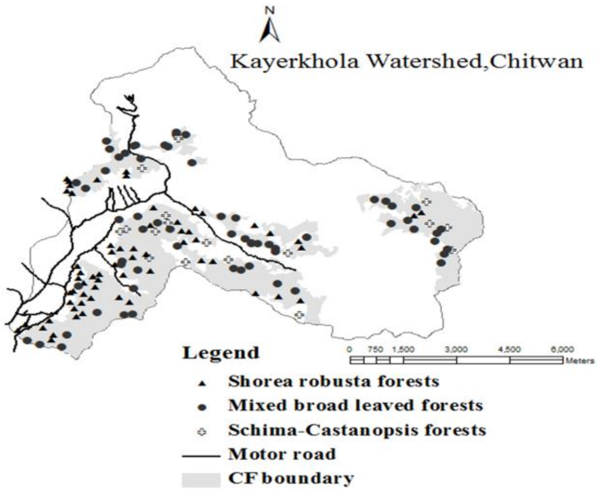


Figure 6.11 Proximity of sample plots from closely located road

6.6. Proximity of forests from settlement

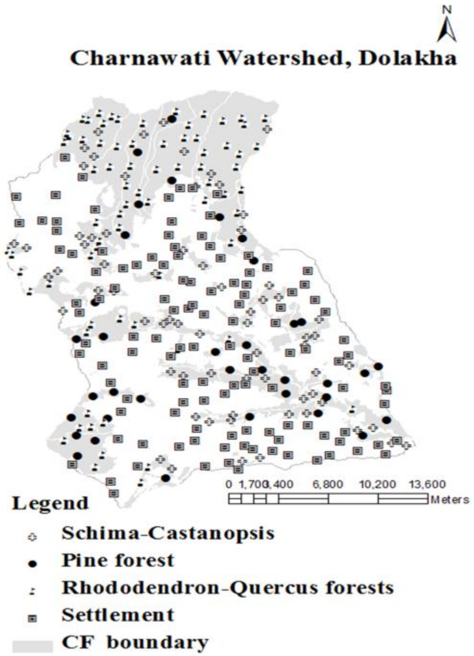
Similar to the proximity to road heads, the location of plots from nearby settlements was found to differ in analysis of satellite images and settlement data (Figure 6.12). Average carbon stock was found to be higher in forest located close to settlements in all vegetation types except *Rhododendron-Quercus* forests and *Schima-Castanopsis* forests (Table 6.3). Carbon stocks in *Schima-Castanopsis* forests were similar in both close and far locations whereas these were more than twice as high in far locations in *Rhododendron-Quercus* forests. According to communities, *Rhododendron-Quercus* species were not useful for timber and they wanted to promote timber trees in their forests; therefore, they may have been more likely to harvest these from nearby locations.

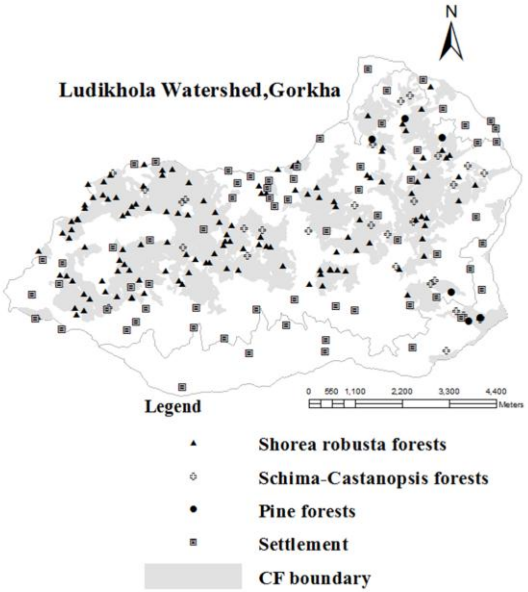
Carbon stock changes were found to be higher in forests located far from the settlements especially in *S. robusta*, mixed broadleaf and *Rhododendron-Quercus* vegetation, whereas the was opposite occurred in the case of *Schima-Castanopsis* and *Pine* forests. Communities explained that, following the inception of CF, they have been working, and even more so since the REDD+ project began, in *Schima-Castanopsis* and *Pine* forests, which could be a reason for increased carbon stocks near some settlements (Table 6.3).

Table 6.3 Proximity (settlement to plots) and average c-stock (MgC/ha in year 2010) and change in C-stock (between 2010-2013, t C/ha) in forests analysing 21 plots located at farthest away and 21 at closest from the local settlement

Vegetation types	Ave. distance (m)	Range (m)	C-stock in 2010(MgC/ha)	Range (MgC/ha)	C-change 2010-2013(MgC/ha)	Range (MgC/ha)
S. robsuta forests	466.9	74.6-252.1	**118.4**#	2.3-307.1	15.5	-26.6-47.2
	1361.0	1073.3-1987.4	113.7	7.8-322.0	**18.0***	-23.4-45.9
Mixed broadleaf forests	438.2	145.2-605.0	**120.7**#	8.0-345.1	14.6	-20.7-41.4
	1299.6	848.9-2265.8	114.1	6.0-310.3	**18.6***	-19.5-45.2
Schima-Catstanopsis	268.8	65.1-385.5	92.6	19.4-228.3	22.8	-17.4-42.0
	1381.9	910-3118.2	93.7	25.4-269.7	10.4	-13.4-37.6
Pine forests	420.5	190.0-559.0	**97.2**#	0.6-230.6	19.5	-21.9-42.9
	995.7	618.3-2842.9	85.6	28.1-184.4	19.3	-16.1-49.6
Rhododendron-Quercus	494.5	104.0-774.4	63.3	6.9-174.0	7.7	-18.6-39.5
	2418.9	1697.0-3490.8	142.7	3.7-243.2	**8.1***	-28.0-33.3

Note: #higher average biomass carbon (above ground and below ground, in 2010) plots located at close from settlement, * higher change in biomass carbon (above ground and below ground, between 2010 and 2013) in plots located at far from settlement





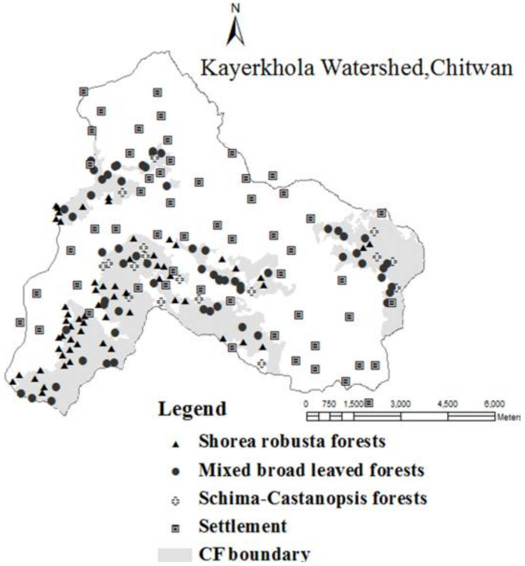


Figure 6.12 Proximity of sample plots from settlement

6.7. Stand age in CFs

Comparatively older trees were found in CFs with *S. robusta* and mixed broad leaf vegetation followed by *Schima-Castanopsis* while younger trees occurred in *Pine* and *Rhododendron-Quercus* vegetation. Carbon stocks in the year 2010 were higher in those CFs which had higher age class trees than lower age class but the positive changes in carbon stock was higher in the CFs which had lower age class of trees in all vegetation (Table 6.4).

Table 6.4 Average age of forest stand, and C-stock in year 2010 (MgC/ha) and C-stock change between 2010 and 2013 (MgC/ha) in CFs by vegetation types

Vegetation	**Age of the forest stand**		**C- stock 2010 (MgC/ha)**		**C- Change 2010-2013 (MgC/ha)**	
	Average	**SD**	**Average**	**SD**	**Average**	**SD**
Shorea-mixed broadleaf (N=10)	25	4.08	112.26	12.59	**14.40**	0.97
	51	9.37	**116.90**	7.33	13.04	1.47
Schima-Castanopsis (N=10)	22	2.58	76.62	8.56	**20.14**$^{\#}$	6.64
	52	8.14	**96.92***	15.20	13.28	5.81
Pine (N=8)	31	4.41	84.12	5.36	**19.77**$^{\#}$	8.48
	42	8.45	**93.95***	21.11	14.82	6.07
Rhododendron. (N=4)	26	4.79	67.39	5.16	**13.11**$^{\#}$	4.00
	42	11.90	**86.60***	16.11	8.01	1.73

Note: * Higher the age of forest stand of CFs had higher carbon stock in year 2010 $^{\#}$ smaller the age of forest stand of CFs had higher positive changes in carbon stock between 2010 and 2013

6.8. Socio-economic aspects of CFUGs

There are several socio-economic aspects of communities which may affect carbon stock in CFs. According to the literature and consultation with experts working in the REDD+ projects and forestry sector in Nepal, per capita forest areas, household level land holding size, live-stock holding, bio-gas use, petroleum energy use, change in quantity of biomass (timber and firewood) extraction, change in grazing livestock, caste heterogeneity, change in quantity of grass collection, change in quantity of fodder collection, charge in quantity of litter collection are all possible socio-economic factors responsible for changing carbon stocks in CFs. Results of analysis about these factors in CFs by different vegetation types (i.e. the dominant vegetation type of CF) are presented in this section.

6.8.1. Per capita forest areas

Analysis of forest area per capita forests and its relationship with carbon stock in CFs was made on the basis of higher and lower size categories for each vegetation type. In the higher size category, *Schima-Castanopsis* forests had higher forest area per capita followed by *S. robusta*-mixed broad leaf forests; this was lowest in *Pine* forests. In the lower category, *Pine* forest had higher per capita area followed by *Rhododendron-Quercus* and the lowest was in *Shorea*-mixed broadleaf forest.

Carbon stock in the year 2010 was highest in CFs which had higher per capita forests available except the CFs with *Rhododendron-Quercus* vegetation (Table 6.5). There were few differences between the mean of larger and smaller per capita forest categories of the *Rhododendron-Quercus* forests which indicates that smaller forest s of this type were not under heavy pressure from communities. In term of changes, *S.robusta* and *Rhododendron-Quercus* forests had higher levels of change in larger per capita forests while the situation was different for the other two vegetation types. Smaller forests located at lower altitudes (*S.robusta)* and higher altitudes (*Rhododendron-Quercus)* experienced comparatively high pressure. But, there might be more care taken in the smaller forests dominated by *Pine* and *Schima-Castanopsis* vegetation located in the mid-hills.

Table 6.5 Per capita forest areas (ha/person) difference and carbon stock in year 2010 and change in carbon stock between 2010–2013 in CFs by vegetation

Vegetation	Per capita forest area in CF (ha)		C stock in 2010 (MgC/ha)		C-change 2010-2013 (MgC/ha)	
	Average	SD	Average	SD	Average	SD
Shorea mixed broadleaf (N=10)	0.02	0.01	108.18	15.58	13.22	2.17
	0.20	0.04	**118.21***	10.23	**14.63**$^{\#}$	1.43
Schima-Castanopsis (N=10 in both case)	0.03	0.01	78.16	11.28	18.71	7.37
	0.43	0.26	**95.82***	13.17	12.02	5.61
Pine (N=8)	0.05	0.02	84.96	15.98	18.52	7.77
	0.15	0.06	**93.11***	15.37	16.07	7.68
Rhododendron-Quercus (N=4)	0.03	0.02	76.52	16.83	8.41	2.01
	0.18	0.10	75.98	14.81	**12.63**$^{\#}$	4.62

Note: *Larger per capita forest had higher carbon stock in year 2010, $^{\#}$ larger per capita forest had higher changes in carbon stock between 2010 and 2013

6.8.2. Household level landholding

Land holding size was found to differ between CFs. Land holdings were larger in communities associated with *Schima-Castanopsis* forests and *Pine* forests followed by *S. robusta* and mixed broadleaf forests and *Rhododendron-Quercus* forests. The carbon stock in year 2010 was higher in CFs with smaller sizes of household level land holding except for *Shorea*-mixed broadleaf forests. The sizes of household level land holdings in *S. robusta* and mixed broadleaf forests were smaller; this may have been because some of the settlements at these locations were comparatively new.

After the REDD+ activities, a higher positive change in carbon stocks was estimated in all CFs (across different vegetation types) which had larger household level agricultural land holdings. Specifically, these changes were higher in *Pine* forests followed by S*chima-Castanopsis* forests and lower in *Rhododendron-Quercus* forests (Table 6.6).

Table 6.6 Household level landholding size and C-stock in year 2010(MgC/ha) and C-stock change between 2010–2013 (MgC/ha) in CFs by vegetation types

Vegetation	**Agriculture land in CF (ha/HH)**		**C- stock in 2010 (MgC/ha)**		**C-stock change 2010 -2013 (MgC/ha)**	
	Average	**SD**	**Average**	**SD**	**Average**	**SD**
Shorea-mixed broadleaf (N=10)	0.50	0.12	114.34	8.04	14.09	1.12
	0.82	0.04	120.32	3.01	**14.92**#	0.41
Schima-Castanopsis (N=10)	0.60	0.09	**90.03***	16.07	12.35	5.74
	0.89	0.05	84.93	14.85	**20.65**#	6.47
Pine (N=8)	0.71	0.07	**90.59***	16.92	12.12	6.05
	0.89	0.05	87.48	15.42	**22.48**#	5.00
Rhododendron. (N=4)	0.66	0.06	**82.33***	14.83	7.36	1.80
	0.81	0.06	76.18	14.58	**12.79**#	4.49

Note: *Smaller per household landholding had higher carbon stock in year 2010, # larger per household agriculture land had higher changes in carbon stock between 2010 and 2013

6.8.3. Average change in livestock

After the REDD+ projects, the average number of livestock changed in CFs. The change in carbon stocks was higher in CFs where positive changes in livestock were estimated in all vegetation types except *Shorea*- mixed forests. According to the communities, people use forest resources for livestock in lower altitude areas (e.g. CFs with *Shorea* forests) where they have less per capita agricultural land and if they reduce livestock that increases biomass carbon in the forests (Table 6.7).

Table 6.7 Household level livestock unit and C-stock in the year 2010 (MgC/ha) and C-stock change between 2010 – 2013 (MgC/ha) in CFs by vegetation types

Vegetation	Change in Livestock unit (HH) in CF		Livestock (per HH) in CF before REDD		C-stock in 2010 (MgC/ha)		C-stock change 2010- 2013 (MgC/ha)	
	Average	**SD**	**Average**	**SD**	**Average**	**SD**	**Average**	**SD**
Shorea-mixed broadleaf (N=10)	-1.08	1.07	1.84	1.65	**114.23***	11.02	**14.08**$^{\#}$	1.54
	1.31	0.54	1.11	1.26	112.54	11.05	13.83	1.54
Schima-Castanopsis (N=10)	-0.96	0.69	2.06	1.12	**85.16***	18.73	12.56	3.74
	0.91	0.47	1.94	1.11	80.81	16.09	**16.90**$^{\#}$	6.28
Pine (N=8)	-0.24	0.84	1.65	1.43	**89.87***	15.12	16.14	8.38
	1.16	0.48	1.39	0.63	88.19	17.30	**18.45**$^{\#}$	7.04
Rhododendron. (N=4)	-0.53	0.88	1.35	0.06	**82.22***	14.05	7.46	2.06
	0.38	0.35	2.03	0.73	74.14	16.81	**10.93**$^{\#}$	3.79

Note: *Reduced LSU at household had higher carbon stock in year 2010 $^{\#}$ Increase in LSU had higher changes in carbon stock between 2010 and 2013

6.8.4. Biogas use

Higher proportions of households in *S.robusta* CFs were using biogas followed by *Schima-Castanopsis* and lowest in *Rhododendron-Quercus* CFs. Of various reasons, the applicability of present technology (which is better for lower altitude areas) and the economic aspect of people (more people could afford to invest in and operate biogas plants in these CFs) may be important.

In 2010, carbon stocks were higher in those CFs where more households were using biogas in *Schima- Castanopsis* and *Pine* forests. Change in carbon stock was higher in the CFs where more households were using biogas except in *S.robusta* forests (Table 6.8). There were similar changes in both higher and less biogas using CFs in *S.robusta* vegetation because communities only collect fallen dry branches for fuel wood and that may not affect carbon change in the forests. Biogas using households were also using firewood for major cooking as they think their biogas stove is not as effective.

Table 6.8 Proportion of biogas using households and C-stock in year 2010 (MgC/ha) and C-stock change between 2010 – 2013 (MgC/ha) in CFs by vegetation types

Vegetation	**Proportion of biogas using HH**		**C-stock in 2010 (MgC/ha)**		**C- change 2010-2013 (MgC/ha)**	
	Average	**SD**	**Average**	**SD**	**Average**	**SD**
Shorea-mix broadleaf (N=10)	0.03	0.02	116.01	8.15	14.32	1.14
	0.19	0.11	114.24	10.89	14.07	1.52
Schima-Castanopsis (N=10)	0.00	0.00	84.95	18.43	11.99	3.71
	0.11	0.13	**102.62***	14.63	**15.57**$^{\#}$	6.49
Pine (N=8)	0.00	0.00	83.07	12.54	15.62	8.62
	0.01	0.02	**95.00***	17.06	**18.98**$^{\#}$	6.48
Rhododendron-Quercus (N=4)	0.00	0.00	78.37	14.44	10.11	4.74
	0.01	0.02	71.25	11.33	**10.46**$^{\#}$	4.36

Note: * Higher biogas using HHs proportion in CFs had higher carbon stock in year 2010 $^{\#}$ Higher biogas using HHs proportion in CFs had higher changes in carbon stock between 2010 and 2013

6.8.5. Petroleum energy use

Similar to biogas energy use, a comparatively higher proportion of household in CFs with *S. robusta* vegetation were using petroleum energy (LP gas and Kerosene) followed by *Schima-Castanopsis*, while the lowest proportion was in *Pine* and *Rhododendron-Quercus* forests. According to local people, petroleum energy was costly in the mountain areas where *Pine* and *Rhododendron-Quercus* forests occur due to higher transportation cost. Therefore, only those people who can afford petroleum energy cost in mountain areas use this energy.

In 2010, there was little difference in carbon stocks between high and low petroleum energy using CFs. But changes in biomass carbon between 2010 and 2013 were higher in those CFs which had higher petroleum energy using households except for *Shorea* and mixed broadleaf forests (Table 6.9). In group discussions, people explained that they kept Liquid Petroleum gas but they used firewood for major cooking such as for feeding livestock, cooking and heating. Mostly, people used LP gas for tea making and other small and quick cooking purposes.

Table 6.9 Proportion of Petroleum energy (LP gas, Kerosene) using households and C-stock in year 2010 (MgC/ha) and change in C-stock between 2010 – 2013 (MgC/ha) in CFs by vegetation types

Vegetation	**Prop. of Petroleum energy using HH**		**C-stock in 2010 (MgC/ha)**		**C- change 2010-2013 (MgC/ha)**	
	Average	**SD**	**Average**	**SD**	**Average**	**SD**
Shorea-mixed broadleaf (N=10)	0.08	0.05	116.53	9.59	14.40	1.34
	0.45	0.08	114.23	8.69	14.07	1.21
Schima-Castanopsis (N=10)	0.00	0.00	80.84	15.77	12.93	4.72
	0.25	0.15	**89.98***	20.78	**17.61**$^\#$	5.13
Pine (N=8)	0.00	0.00	81.88	9.76	17.21	8.63
	0.04	0.04	**96.19***	17.81	**17.39**$^\#$	6.96
Rhododendron. (N=4)	0.00	0.00	76.52	16.83	8.41	2.01
	0.05	0.04	75.98	14.81	**12.63**$^\#$	4.62

Note: * Higher Petroleum using HHs proportion in CFs had higher carbon stock in year 2010 $^\#$ Higher Petroleum using HHs proportion in CFs had higher changes in carbon stock between 2010 and 2013

6.8.6. Biomass extraction

Communities are extracting firewood and timber as major forest products from their CFs (Table 6.10). Before the REDD+ activities, extraction was highest in *Shorea*-mixed broadleaf CFs followed by *Schima-Castanopsis* and lowest in *Rhododendron-Quercus* forests. Local communities harvest higher biomass in CFs where carbon stock was higher in year 2010.

After the REDD+ project, communities either reduced or maintained their levels of biomass extraction from forests. The reduction in the quantity of biomass (firewood and timber) extracted and the incremental increase in biomass were both greatest in *S. robusta* –mixed broadleaf CFs. The lowest reduction in biomass extraction was in *Rhododendron-Quercus* forests and lowest increase in biomass quantity was in *Pine* forests. Carbon stock changes (between 2010 and 2013) were highest in those CFs which had reduced biomass extraction by the greatest extent (Table 6.10).

Table 6.10 Change in quantity of biomass extraction (both timber and firewood) and C-stock in year 2010 (MgC/ha) and C-stock change between 2010 – 2013 (MgC/ha) in CFs by vegetation types

Vegetation	**Change extraction (before and after REDD+) (Mg)**		**Extraction before REDD+(Mg)**		**C- stock in 2010 (MgC/ha)**		**C-stock change 2010-2013 (MgC/ha)**	
	Ave.	**SD**	**Ave.**	**SD**	**Ave.**	**SD**	**Ave.**	**SD**
Shorea-mixed broadleaf (N=10)	-11.92	11.31	18.53	21.09	**121.58***	2.52	**15.10**$^{\#}$	0.35
	4.24	10.47	11.27	19.76	103.44	13.10	12.56	1.82
Schima-Castanopsis (N=10)	-2.96	2.94	12.21	10.34	**99.65***	14.15	**19.30#**	5.68
	2.24	1.70	12.18	11.86	82.63	16.79	11.26	2.94
Pine (N=8)	-5.39	6.28	6.47	7.01	**91.26***	19.12	**19.12**$^{\#}$	7.59
	0.08	0.36	10.03	12.28	86.81	12.36	15.47	7.59
Rhododendron. (N=4)	-0.16	0.28	1.10	1.02	76.28	15.39	**12.69**$^{\#}$	4.54
	1.06	1.32	2.55	2.04	77.71	17.14	8.43	1.91

Note: * Lower biomass extraction in CFs had higher carbon stock in year 2010; $^{\#}$ Lower biomass extraction in CFs had higher changes in carbon stock between 2010 and 2013; Ave. means average; SD means standard deviation

The REDD+ pilot project supported the provision of biogas and ICS to reduce the quantity of firewood used. The project distributed ICS to 6% households and biogas plants to 3% of households in *S. robusta* mixed broadleaf CFs. Similarly, there were distributions of ICS to 11% and biogas to 1% of households of *Schima-Castanopsis* CFs; ICS to 10% and Biogas to 1% of households of Pine forests; and ICS to 15% and Biogas to 1% of households of *Rhododendron-Quercus* CFs (ICIMOD 2014). It is evident that ICS was distributed to more household in higher altitude CFs whereas biogas plants were supported to more households of lower altitude CFs. These interventions may have played some role in the increase in biomass carbon in these CFs.

6.8.7. Grazing

Livestock grazing was analysed by using LSU day in the forests. Before REDD+ project activities, highest LSU grazing occurred in *Schima-Castanopsis* forests and lowest in *Rhododendron-Quercus* forests. Higher levels of livestock grazing in CFs were associated with higher carbon stock in 2010. This means grazing in the forest had almost no impact on the carbon stocks maintained in CFs. Reductions in livestock grazing occurred in CFs after the REDD+ project; these were highest in *Shorea*-mixed broadleaf forests followed by *Schima-Castanopsis* forest and lowest in *Pine* forests. The study found higher reductions in livestock grazing in CFs which had higher carbon stock in year 2010. This shows the consciousness of the people in protecting forests before the REDD+ project in CFs which had more reduction in grazing due to project intervention. A higher positive change in carbon stock was found in the CFs where reductions in livestock grazing were higher (Table 6.11).

Table 6.11 Grazing (Live Stock Unit days in a year) and C-stock in year 2010 (MgC/ha) and C-stock change between 2010–2013 (MgC/ha) in CFs by vegetation types

Vegetation type	**Change grazing (days/yr) (before and after REDD+)**		**Livestock grazing (days per year) before REDD+**		**C-stock in 2010 (MgC/ha)**		**C-change in 2010 and 2013 (MgC/ha)**	
	Ave	**SD**	**Ave**	**SD**	**Ave**	**SD**	**Ave**	**SD**
Shorea-mixed broadleaf (N=10)	-12397.30	12495.70	23036.33	13742.10	**116.83**[*]	10.13	**14.40**[#]	1.42
	0.00	0.00	0.00	0.00	114.37	9.43	14.09	1.31
Schima-Castanopsis (N=10)	-7903.10	5225.16	28496.57	16617.19	**90.92**[*]	16.72	**16.21**[#]	6.26
	0.00	0.00	0.00	0.00	92.17	22.65	12.47	3.41
Pine (N=8)	-567.75	1605.84	3090.00	8739.84	85.68	11.15	**19.06**[#]	7. 56
	0.00	0.00	0.00	0.00	92.39	19.48	15.53	7.65
Rhododendron-Quercus (N=4)	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

Note: [*]Reduced grazing days in CFs had higher carbon stock in year 2010 [#]Reduced grazing days in CFs had higher increment in carbon stock between 2010 and 2013; Ave. means average; SD means standard deviation

6.8.8. Caste heterogeneity

The study found the highest index of caste heterogeneity in *Shorea*-mixed broadleaf forests followed by *Rhododendron-Quercus* forests and lowest in *Schima-Castanopsis* and *Pine* forests. Forest types may therefore also reflect caste heterogeneity. While in analysis, all CFs with higher carbon stock in the reference year 2010 were managed by heterogeneous communities except *S. robusta* and mixed broadleaf vegetation types. There change differences were fewer in carbon stock (between 2010 and 2013) between CFs with higher and lower caste heterogeneity indices. The change was highest in *Shorea* mixed broadleaf forests where there was the lowest caste heterogeneity index and almost same in *Rhododendron-Quercus* vegetation. In *Schima- Castanopsis* and *Pine* CFs, a higher positive change in carbon stock with higher caste heterogeneity was found (Table 6.12).

Table 6.12 Caste heterogeneity and C-stock in year 2010 (MgC/ha) and C-stock change between 2010–2013 (MgC/ha) in CFs by vegetation types

Vegetation type	**Caste heterogeneity index in CFs**		**Biomass C stock in 2010 (MgC/ha)**		**Change in biomass C (MgC/ha between 2010 and 2013)**	
	Average	**SD**	**Average**	**SD**	**Average**	**SD**
Shorea-mixed broadleaf (N=10)	0.12	0.10	115.87	9.99	14.30	1.39
	0.63	0.03	110.86	15.70	13.60	2.19
Schima-Castanopsis (N=10)	0.04	0.04	88.87	15.22	17.18	7.31
	0.53	0.04	**89.12**[*]	14.34	**17.59**[#]	6.56
Pine (N=8)	0.24	0.13	87.73	19.17	15.30	6.69
	0.49	0.07	**90.34**[*]	12.57	**19.29**[#]	8.30
Rhododendron-Quercus (N=4)	0.23	0.17	78.84	14.86	10.12	4.63
	0.56	0.07	**79.66**[*]	15.38	10.03	4.66

Note: [*]Higher the caste diversity in CFs had higher carbon stock in year 2010 [#] Higher the caste diversity in CFs had higher changes in carbon stock between 2010 and 2013

6.8.9. Quantity of grass collection

The quantities of changes in grass collection (positive and negative) in the REDD+ CFs are presented by vegetation type in Table 6.13. Average negative changes in grass collection were found to be highest in *Shorea*-mixed broadleaf forests followed by *Schima-Castanopsis* and *Pine* and lowest in *Rhododendron-Quercus* forests. Positive changes in grass collected were found to be highest in *Schima-Castanopsis* vegetation followed by *Rhododendron-Quercus* forests.

Before the REDD+, the highest level of grass collection was from *Shorea*-mixed broadleaf forests followed by *Schima-Castanopsis* forests; this was much reduced after the REDD+. CFs which had the highest reductions in grass collected during the REDD+ project had higher carbon stocks in the year 2010. One of the reasons behind that was due to less grass available in the higher biomass forests with dense canopy than sparse one. CFs which had no reduction or small increment in the quantity of grass collection had the highest increment of carbon stock of all the vegetation types (Table 6.13). This indicates that the forest management communities were not affecting biomass during grass cutting which could help to increase carbon stock in their forests by creating a better environment for tree growth.

Table 6.13 Quantity of grass collection and C-stock in year 2010 (MgC/ha) and C-stock change between 2010 – 2013 (MgC/ha) in CFs by vegetation types

Vegetation	**Change in grass collection (Mg)**		**Grass collection before REDD (Mg)**		**C-stock in 2010 (MgC/ha)**		**C-change (MgC/ha between 2010 and 2013)**	
	Ave	**SD**	**Ave**	**SD**	**Ave**	**SD**	**Ave**	**SD**
Shorea-mixed broadleaf (N=10 in both case	-67.30	84.78	207.01	250.46	117.23	9.59	14.49	1.34
	0.63	3.61	106.16	274.74	118.47	5.49	**14.66**$^{\#}$	0.77
Schima-Castanopsis (N=10)	-59.44	76.04	172.50	163.02	**94.01***	21.98	14.43	4.23
	6.08	16.40	31.21	35.94	83.82	13.34	**16.55**$^{\#}$	7.78
Pine (N=)	-17.08	6.81	90.83	51.22	**95.36***	19.76	15.80	6.94
	0.28	4.49	67.70	114.92	82.71	6.91	**18.80**$^{\#}$	8.34
Rhododendron-Quercus (N=4)	-12.76	6.86	51.00	20.65	76.52	16.83	8.41	2.01
	4.14	5.81	59.18	40.05	79.66	15.38	**10.03**$^{\#}$	4.66

Note: * Less grass collection in CFs had higher carbon stock in year 2010 $^{\#}$ Higher grass collection had higher changes in carbon stock between 2010 and 2013; Ave. means average; SD means standard deviation

6.8.10. Fodder collection

Fodder collection was reduced in CFs with both *Shorea*-mixed broadleaf and *Schima-Castanopsis* vegetation while there was little change in fodder collection in *Pine* and *Rhododendron-Quercus* forests for the REDD+ project. Before the REDD+ project activities, fodder collection was highest in *Shorea*-mixed broadleaf forests followed by *Schima-Castanopsis* forests.

People were collecting fodder in the sparse forests where less carbon stock was available but the highest collection was from the forests with high carbon stock. It seems the quantity of fodder collection has little effect on carbon stock changes in CFs (Table 6.14). This could be due to the consciousness of communities around protection of seedlings and saplings during fodder collection in all CFs.

Table 6.14 Quantity of fodder collection, and C-stock in year 2010 (MgC/ha) and C-stock change between 2010 – 2013 (MgC/ha) in CFs by vegetation types

Vegetation	Change in fodder collection (Mg)		Grass collection before REDD (Mg)		C-stock in 2010 (MgC/ha)		C-stock change 2010-2013 (MgC/ha)	
	Ave	**SD**	**Ave**	**SD**	**Ave**	**SD**	**Ave**	**SD**
Shorea-mixed broadleaf (N=10)	-40.06	89.87	291.7	719.7	110.76	10.30	13.58	1.44
	0.30	0.95	3.5	11.2	**117.03***	10.22	14.46	1.42
Schima-Castanopsis (N=10)	-56.67	149.85	79.9	188.6	85.21	16.13	16.65	5.75
	0.13	0.42	22.8	72.2	**85.94***	19.19	14.00	5.29
Pine (N=8)	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Rhododendron-Quercus (N=4)	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

Note: * Less fodder collection in CFs had higher carbon stock in year 2010 $^{\#}$ Less fodder collection had higher changes in carbon stock between 2010 and 2013; Ave. means average; SD means standard deviation

6.8.11. Litter collection

Reduction of litter collection was highest in CFs with *Schima-Castanopsis* forests followed by *Shorea*-mixed broadleaf forests and lowest in *Pine* and *Rhododendron-Quercus* forests (Table 6.15). This was reduced according to the quantity collection before the REDD+ (i.e. the higher the quantity collected before, the higher the reduction after the REDD+). Litter collection was highest in *Schima-Castanopsis* forests followed by *Shorea*-mixed forests. According to the communities, *Pine* needles were not collected for livestock bedding because they do not easily decompose for manure (used for agriculture crops).

Carbon stocks were high in the year 2010 where litter collection was high in all the forests except *Schima-Castanopsis* where slightly different carbon stock was estimated. This is potentially because higher biomass was associated with higher litter production in the forests. Carbon stock changes between 2010 and 2013 were different in different vegetation types with changed quantities of litter collection. Although there are no clear trends in the results of any of the CFs, higher carbon stock changes were found in *Schima-Castanopsis* and *Rhododendron-Quercus* CFs, where litter collection was highly reduced (Table 6.15). This was because communities preferred not to collect *Pine* needles and *Shorea* leaves as litter as these take time to decompose.

Table 6.15 Quantity of litter collection, and C-stock in year 2010 (MgC/ha) and change in C-stock between 2010 – 2013 (MgC/ha) in CFs by vegetation types

Vegetation	Change in litter collection (Mg)		Litter collection before REDD+ (Mg)		C-stock in 2010 (MgC/ha)		C-stock change 2010 -2013 (MgC/ha)	
	Ave	**SD**	**Ave**	**SD**	**Ave**	**SD**	**Ave**	**SD**
Shorea-mixed broadleaf (N=10)	-9.16	18.03	30.98	55.12	109.34	12.52	13.39	1.75
	1.54	3.91	19.67	42.94	**117.36***	10.26	14.51	1.43
Schima-Castanopsis (N=10)	-11.74	19.58	41.04	66.91	93.90	15.82	**16.54**#	8.14
	0.97	1.16	18.00	22.25	90.65	18.98	14.62	5.80
Pine (N=8)	-1.83	2.79	12.81	11.02	80.95	10.79	16.58	7.76
	0.83	2.36	3.50	8.18	**97.11***	16.24	18.01	7.84
Rhododendron-Quercus (N=4)	-1.22	1.17	12.02	7.33	73.96	16.84	**10.97**#	3.87
	0.79	1.14	3.62	4.18	**82.22***	14.05	7.46	2.06

Note: * Higher litter collection in CFs had higher carbon stock in year 2010 # Less litter collection had higher changes in carbon stock between 2010 and 2013; Ave. means average; SD means standard deviation

6.9. Conclusion

With REDD+ interventions, local communities reduced the incidence of biomass reducing factors which was observed during the annual inventory. There were various factors involved in changing biomass carbon from the reference year to after REDD+ interventions. Of these, the elevation of forests, dominant species, proximity of the forests to road head and settlement are major biophysical factors playing a role in the change in biomass carbon in CFs. Similarly, the size of the forests, size of agriculture land holdings, livestock herd size, the use of alternative energy sources (Bio-gas, Petroleaum energy) and biomass extraction (timber and firewood) are socio-economic factors tending to affect biomass carbon in CFs.

Although CF is contributing to the improvement of forests under business-as-usual scenarios, they are able to further increase carbon stocks by changing existing behaviours associated with forest management and use. There is likely to be a change in existing practices of communities for REDD+ benefits, but those changes may increase costs or lead to the sacrifice of benefits for communities. These sacrificed benefits in the name of carbon benefits can be higher if communities' members have only one option if the source of forest products is CFs and they are highly dependent on forest products for their livelihood. These sacrificed benefits may need to be compensated by the REDD+ carbon benefits to make the REDD+ mechanism effective for long run. However, carbon growth in a forest has biological limitations that will reach at equilibrium stage and have no further scope. Those forests at the equilibrium stage may not get carbon payments based on REDD+; and additionally the communities may be contributing and expecting benefits. This situation may need to be addressed in the future. Estimation of such added costs is important in the design of an effective REDD+ for CF. The next chapter presents evidence of trade-offs between community foregone sacrificed benefits and carbon benefits for REDD+.

CHAPTER SEVEN

TRADE-OFF BETWEEN SACRIFICED BENEFIT TO COMMUNITIES AND CARBON BENEFITS IN CFs

7.1. Introduction

The previous chapter gave results for the major factors affecting carbon stock changes in CFs. This chapter describes the benefits sacrificed by communities to generate per unit carbon benefits in CFs. The overarching goal of this chapter is to identify and estimate trade-offs between carbon stocks and net sacrificed community benefits in the REDD+ CFs.

This chapter is divided into four sections. The next section gives an overview of the additional contributions made by communities for the REDD+. This section quantifies annual contributions made for meetings, plantation, guarding, fire control, silviculture operations and the harvesting of forest products for the REDD+. The third section presents findings about changes in forest resource use practices in CFs and total foregone benefits sacrificed by reducing forest resource extraction for the REDD+. The final section concludes the chapter.

7.2. Contribution of communities for REDD+

According to the group discussions, communities are putting additional effort into meetings, plantation, guarding, fire control, silviculture operations and the harvesting of forest products for the REDD+ project. These added efforts have costs. After identifying community efforts for each year, the differences between average annual costs in the 3 years before REDD+ and 3 years during REDD+ were estimated for CFs by dominant vegetation type (Table 7.1). Similarly, the change in costs due to changed forest management activities for REDD+ was estimated and is presented in Table 7.2. In management practices, CFs with dominant *Pine* species had highest costs followed by *S. robusta* forests, *Rhododendron-Quercus* forests and *Schima-Castanopsis* forests, respectively. Among management costs, the cost associated with executive committee meetings and GAs was higher than other activities in all vegetation types. The meeting costs were highest in *S. robusta* forest and lowest in *Schima-Castanopsis* forests, while harvesting costs which applied predominantly in *S. robusta* forests were reduced after the REDD+ project.

Table 7.1 Participant number (person/ha/yr) in meetings and general assembly and forestry activities costs in the CFUGs (US$/ ha/yr) by vegetation type (3 years before and during 3 years of REDD+) in the study sites

Vegetation types	**[1]Meeting (person/ha/yr)**		**[2]G A (person/ha/yr)**		**[3]Plantation cost (US$/ha/yr)**		**[4]Guarding (US$/ha/yr)**		**[5]fire control (US$/ha/yr)**		**[6]Forestry operation (US$/ha/yr)**		**[7]Harvesting cost(US$/ha/yr)**	
	Before	**After**	**Before**	**After**	**Before**	**After**	**Before**	**After**	**Before**	**After**	**Before**	**After**	**Before**	**After**
Shorea[a]	1.45	1.90	1.45	1.67	0.54	1.38	3.89	6.61	1.09	2.31	1.47	2.62	15.16	8.41
Schima [b]	0.88	1.00	0.82	0.92	0.57	1.45	0.63	0.84	0.21	0.33	0.36	0.74	0.00	0.01
Pine[c]	1.45	1.72	1.58	1.74	0.20	0.66	1.08	1.62	0.35	0.64	0.88	1.62	0.05	0.06
Rhododendron[d]	1.21	1.46	1.04	1.16	0.00	0.38	0.41	0.47	0.00	0.00	0.22	0.86	0.00	0.00

Note: [a]*S. robusta* mixed broadleaf such as *Lagerstroemia parviflora* (Botdhairo), *Terminalia* spp, *Anogeissus latifolia* (Bajhi), *Dalbergia sissoo*, *Syzygium cumini* (Jamun); [b] *Schima- Castanopsis*; [c]Pine dominated; [d]*Rhododendron- Quercus;* [1]Participants in executive committee meeting; [2]participants in general assembly in CFs; [3]Labour cost and material cost used for plantation in CFs, [4]Labour cost for guarding forests from illegal activities; [5]cost for fire line preparation and forest fire control in CFs, [6]labour and material cost for silviculture operation in CFs, [7]labour and material costs for timber and fuel wood harvesting in CFs

Table 7.2 Cost of the CFUGs (US$/ ha/yr) by vegetation type due to changed forest management practices after REDD+ in the study sites

Vegetation types	**Meeting (US$)**	**Plantation (US$)**	**Guarding (US$)**	**Fire control (US$)**	**Silviculture operation (US$)**	**Harvesting (US$)**	**Total cost (US$)**
Shorea[a]	5.15	0.84	2.71	1.22	1.15	-6.75	4.32
Schima [b]	1.96	0.88	0.20	0.12	0.38	0.00	3.56
Pine[c]	3.73	0.46	0.54	0.29	0.74	0.00	5.76
Rhododendron[d]	2.55	0.38	0.06	0.00	0.65	0.00	3.64
Total	3.19	0.79	1.00	0.47	0.68	-2.07	4.05

Note: : [a]*S. robusta* mixed broadleaf such as *Lagerstroemia parviflora* (Botdhairo), *Terminalia* spp, *Anogeissus latifolia* (Bajhi), *Dalbergia sissoo*, *Syzygium cumini* (Jamun), [b] *Schima- Castanopsis*, [c]Pine dominated, [d]*Rhododendron- Quercus*; -sign is benefits or reduced costs of the communities; 85NRs=1US$

7.3. Changed forest product use practices of communities for REDD+

Annual forest product use practices in each CF were estimated and average annual quantity used before and during REDD+ project was estimated and presented (Table 7.3). Most of the CFUGs in the study sites were using eight forest products, namely timber, fuel wood, grass, fodder, litter, grazing cow, grazing goat and NTFP income. Foregone sacrificed benefits due to reducing timber harvest were highest in *Pine* forests followed by *S. robusta* mixed broadleaf and lowest in *Rhododendron-Quesrcus* forests. Among all foregone sacrificed benefits items, timber was highest in the case of *S.robusta* forests and *Pine* forests, whereas stall feeding (reduced grazing) livestock was highest in *Schima-Castanopsis* forests and grass cutting was highest in *Rhododendron-Quercus* forests (Table 7.4). By contrast, CFs with *Pine* and *Schima-Castanopsis* vegetation types had positive changes in NTFP benefits. According to communities, NTFP business is increasing, especially the use of herbs and shrubs, which involve comparatively less biomass loss than trees.

Table 7.3 Average annual forest product collection and income from NTFP in CFUGs by vegetation types (3 years before and during 3 years of REDD+) in the study sites

Vegetation types	**[1]Timber (m^3/ha)**		**Fire wood (Bhari/ha)**		**Grass (Bhari/ha)**		**Fodder (Bhari/ha)**		**Litter (Bhari/ha)**		**Cow grazing (numbers/ha)**		**Goat grazing (numbers/ha)**		**Income NTFP (US$/ha)**	
	Before	**After**	**Before**	**After**	**Before**	**After**	**Before**	**After**	**Before**	**After**	**Before**	**After**	**Before**	**After**	**Before**	**After**
Shorea[a]	0.19	0.15	41.03	32.42	56.12	45.47	37.43	32.39	8.12	6.91	79.73	36.41	272.77	159.93	0.15	0.10
Schima [b]	0.10	0.09	11.62	8.47	24.45	19.70	7.84	3.53	13.87	12.83	60.67	43.65	118.93	87.34	1.10	11.70
Pine[c]	0.19	0.11	9.60	9.13	42.46	37.96	0.00	0.00	5.46	5.13	15.57	12.50	97.93	81.36	19.40	30.21
Rhododendron[d]	0.03	0.03	13.18	12.41	26.50	24.30	0.00	0.00	4.63	4.51	0.00	0.00	0.00	0.00	0.00	0.00

Note: [a]*S. robusta* mixed broadleaf such as *Lagerstroemia parviflora* (Botdhairo), *Terminalia* spp, *Anogeissus latifolia* (Bajhi), *Dalbergia sissoo*, *Syzygium cumini* (Jamun);, [b] *Schima- Castanopsis*; [c]Pine dominated; [d]*Rhododendron- Quercus;* [1]Timber quantity includes total quantity of timber harvesting in CF in this table but the value (given in Table 7.4) was estimated separately because price rate is different for timber of different tree species.

Table 7.4 Average annual cost (US$/ha) of the CFUGs due to changing forest product use behaviour for the REDD+ by vegetation types of the study sites

Vege. types	Timber	Fuel-wood	Grass	Fodder	Litter	[1]Cow feeding	[2]Goat feeding	NTFP income	Total lost
Shorea[a]	39.64	15.31	14.58	6.97	0.98	28.90	39.02	0.00	145.41
Schima[b]	5.77	2.99	6.37	5.58	0.73	11.06	10.28	+0.12	42.65
Pine[c]	42.38	16.01	5.83	0.00	0.23	1.98	5.36	+0.13	71.66
Rhodo[d]	+1.59	1.02	2.85	0.00	0.09	0.00	0.00	0.00	2.37
Total	19.96	8.16	8.60	4.99	0.71	14.76	17.86	+0.08	74.96

Note: [a]*S. robusta* mixed broadleaf such as *Lagerstroemia parviflora* (Botdhairo), *Terminalia* spp, *Anogeissus latifolia* (Bajhi), *Dalbergia sissoo*, *Syzygium cumini* (Jamun), [b]*Schima- Castanopsis* , [c]Pine dominated, [d]*Rhododendron- Quercus;* *[1,2]*Cow and Goat feeding costs include added costs due to reduced grazing; + sign is increased benefits of the communities, no sign is lost benefits, 85NRs=1US$

Total annual sacrificed forgone benefits, annual contribution, total added costs (sum of sacrificed benefits and contributions) and annual carbon gain differed in CFs by vegetation type (Table 7.5). Highest sacrificed community benefits were estimated in *S. robusta* and mixed broadleaf forests followed by *Pine* forest and lowest in *Rhododendron-Quercus* forests. In terms of contribution, communities who were managing *Pine* forests had the highest additional costs followed by *Shorea* and mixed broadleaf forests; the lowest were in *Shima-Castanopsis* forests. In total, the highest additional cost to communities (equal to US$149.73) was for managing one hectare of *S. robusta* and mixed broadleaf forests after the REDD+ project whereas the lowest (equal to US$6.01) was in *Rhododendron-Quercus* forests. However, these foregone benefits may change with change in forest product prices and labour wage rates. Possible changes in these prices are discussed in next chapter.

Associated with these additional costs of communities, different carbon quantities were gained in CFs. There was a similar trend observed for annual carbon gains and community contributions in CFs; this was highest in *Pine* forests followed by *Schima-Castanopsis* forests and lowest in *Rhododendron-Quercus* forests. In terms of total costs (sacrificed foregone benefits and contributions), CFs with *S. robusta* and mixed broad leaf forests had the highest costs (US$149.73 per ha), followed by *Pine* forests (US$ 77.42) while the lowest was in *Rhododendron-Quercus* forests (US$ 6.01). On average, communities have invested efforts equivalent to US$79.01 per year to gain 5.1 Mg of carbon in CFs. This equals an annual total cost to communities of US$15.5 per unit of carbon (Table 7.5).

Considering the 100 year time horizon of the present carbon increment, this study estimated the highest carbon benefits (US$4.75) in *Pine* forests followed by *Schima-Castanopsis* (US$ 4.61) and lowest in *Rhododendron-Quercus* forests. On average, all CF communities have increased carbon quantities through REDD+ activities at an annual value of US$1.32 per ha assuming the present price of US$7 per $MgCO_2e$ is static into the future. However, if the market mechanism for carbon price improves (assuming an optimistic rate of US$20 price per $MgCO_2e$), this will rise to US$3.76 per ha. On the other hand, if the carbon market worsens, the price could go down to the lowest range of the voluntary market (US$1.2 per $MgCO_2e$) and CFUGs would only get US$0.23 per ha (Table 7.5). Among the different vegetation types, the highest income will likely be realised by *Pine* dominated forests followed by *Schima-Castanopsis* and the lowest by *Rhododendron-Quercus* forests.

Table 7.5 Sacrificed benefits of communities for the REDD+ in CFs by vegetation types in the study area

Species domination in CF	**Foregone benefits[1] (US$/ ha/yr)**	**Added contribution[2] (US$/ ha/yr)**	**Total Cost[3] (US$/ ha/yr)**	**Average change[4] MgC/ha (from 2010-2013)**	**Average annual change[5] MgC/ha**	**Ave change[6] $MgCO_2e$ /ha**	**Annual carbon benefit[7] $MgCO_2e$ /ha (in 100 yr time horizon)**	**C benefits[8] per ha at US$ 20/$MgCO_2e$**	**C benefits[9] per ha at US$ 7/$MgCO_2e$**	**C benefits[10] per ha at US$ 1.2/$MgCO_2e$**
S. robusta mixed	145.41	4.32	149.73	15.70	5.23	19.19	0.19	$3.84	$1.34	$0.23
Schima-Castanopsis	42.65	3.56	46.21	18.84	6.28	23.03	0.23	$4.61	$1.61	$0.28
Pines dominated	71.66	5.76	77.42	19.43	6.48	23.75	0.24	$4.75	$1.66	$0.29
Rhododendron-Quercus	2.37	3.64	6.01	6.78	2.26	8.29	0.08	$1.66	$0.58	$0.10
Total	74.96	4.05	79.01	15.4	5.13	18.82	0.19	$3.76	$1.32	$0.23

Note: [1] Foregone sacrificed benefits include costs due to change in forest products uses before and after the REDD+, currency conversion rates 1 US$=85NRs is used (during data collection date February 2012),

[2] Added contribution includes costs added due to forest protection and forest development activities (meeting, fire control, guarding, plantation, silviculture operation),

[3] Total cost is sum of sacrificed benefits and cost for added contributions,

[4] Average changes in total biomass carbon (both above ground and below ground) between 2010 and 2013

[5] Average annual changes in carbon stock (MgC/ha)

[6] Carbon benefit (CO_2e) MgC/ha is estimated from biomass carbon multiplying by 3.67

[7] Carbon benefit (CO_2e) MgC/ha per year considering permanence issue (for 100 year time horizon as suggested) (Fearnside 2002)

[8] Carbon benefit per ha per year assuming optimistic rate US$20 per ton

[9] Carbon benefit per ha per year assuming continuation of present rate US$7 per ton for REDD+

[10] Carbon benefit per ha per year assuming worse market condition and pessimistic rate US$ 1.2 per ton

7.4. Conclusion

These results show that there is a higher trade-off of community benefits for potential carbon benefits for the REDD+ project. Communities' direct costs for REDD+ activities exceeds carbon benefits. The price of timber price and the labour cost for meetings and other forestry activities are main causes for the higher cost to communities. Highest cost were found in *Schima-Castanopsis* forests and lowest in *Rhododerndron-Quercus* forests while higher carbon benefits were obtained in *Pine* forests and lowest in *Rhododerndron-Quercus* forests. However, most of the CFUGs are organizing forestry activities and meetings and assemblies during the leisure time of the majority of people. These therefore have lower opportunity costs as people are doing these activities during their free time. Since the conservation and enhancement of carbon stocks in forests would be the main aim of CFUGs together with the country's commitment under REDD+, communities can decide on the level of efforts they wish to contribute. However, they are unlikely to increase their effort further if their additional costs exceed additional income from carbon in the long term. At that stage, communities may not be interested in REDD+. The next chapter presents a discussion about the results of the study by relating these to the various issues, theories and findings published in the existing literature.

CHAPTER EIGHT

DISCUSSION OF FINDINGS

8.1. Introduction

This chapter builds upon the findings in previous chapters to explore the state of knowledge and ongoing issues for the REDD+ mechanism and CFs.

The chapter are divided into various sections. Each section deals with a particular issue with regards to the REDD+ mechanism and CFs based on the results of this study and the relevant literature. The section 8.2 gives community-based forest management regime, rural livelihoods and REDD+; The section 8.3 gives tree size distribution in community based forest management under the REDD+ mechanism; the section 8.4 covers changes in carbon stock in CFs under the REDD+ mechanism ; the sections 8.5 discuss about potential carbon growth in CFs; the section 8.6 gives key factors affecting carbon stock in CFs ; The section 8.7 gives trade-off between communities sacrificed benefits and carbon benefits in CFs; the section 8.8 explains performance of REDD+ projects in CFs. The section 8.9 gives contemporary issues in REDD+, the section 8.9 gives REDD+ CFs and the Section 8.10 gives ideal CFs for REDD+ benefits respectively.

8.2. Community-based forest management regime, rural livelihoods and REDD+

While over 7% of global forests are under community management (FAO 2011), this form of forest management is increasingly popular in developing countries with more than 22% of all forests in developing countries under this form of management (Nurse & Malla 2006). This is especially the case in Asia and Africa (White & Martin 2002; Nurse & Malla 2006); over 25% of total forests in Nepal are community managed. The initial aim of CF was to improve forest condition by involving local communities in the management of local forests and to provide opportunities to meet their susbsistance need for forests resources (Arnold 1991; Luckert 1999). Most of these forest management communities are poor and use forest resources for livelihood support (Sunderlin *et al.* 2005). Such communities use forest products in conservative ways which have helped to improve forests, meet their needs for forest products and generate income (Dev *et al.* 2003). However, the existing benefits derived from such practices can be potentially further enhanced by incorporating incentive mechanisms such as REDD+. As discussed earlier, the REDD+ mechanism offers opportunities to both increase carbon stock in forests and reduce local poverty. This is supported by the finding of a previous study that CFs can contribute in reducing atmospheric GHGs (Maraseni *et al.* 2005). Such incentives can encourage local communties and govement to initiate REDD+ projects in Nepal. In providing support for both communties and forests (Kellert *et al.* 2000), the proposed REDD+ mechanism would incentivise the conservation efforts of communitties. While the REDD+ mechanism is evolving and policy frameworks are being formulated at international and national levels (Cerbu 2011), special consideration is necessary for CF systems that respects the subsistance forest product needs of communities, generates income and engages communities at the local level (MFSC 2013). This study shows all CFs have potential to increase carbon stocks however the quantity of carbon stock changes varies; hence, there is an opportunity to provide incentive to forest dependent communties to increase carbon sequestration capacity of forests and generate socio-economic benefits.

8.3. Tree size distribution in community based forest management under REDD+ mechanism

The decline in stocking rates of large-diameter tree size classes often but not always follows a reverse-J-shaped distribution (Hitimana *et al.* 2004).The reverse-J shaped distribution indicates the equilibrium structure of forests with similar mortality rates across the entire range of diameters particularly in less disturbed uneven aged forests (Chen & Bradshaw 1999; Nyland 1996). However, some size trees could be missing in disturbed forests (Hitimana *et al.* 2004) resulting in a changes in the size distribution pattern. Similar to Hitimana *et al.* (2004), results presented in Chapter 4 indicate that most of the CFs in this study tended towards a reverse j-shaped distribution pattern of trees with different diameter size. However, the distribution pattern in the study CFs varied with vegetation type in the reference year of 2010. Tree size distribution in these forests also changed with REDD+ project activities over the 2010–2013 period. These differences could be the outcomes of forest management activities of CFUGs but may also be due to site factors (Hitimana *et al.* 2004). Site factors such as soil are unlikely to change over short timeframes (Paul *et al.* 2002) though they may reflect the impact of past management activities. This study found dense canopy CFs had higher stocking rates of larger trees than did sparse canopy CFs. As reported elsewhere (Connell *et al.* 1984; Smith *et al.* 1997), this finding might also be due to the lower productivity of sparse canopy sites. As mentioned by Acharya (2002), forests canopy structures have been improved after community management. As improvement of forest vegetation helps to increase the productivity of forest sites (Pretzsch 2010), gradual improvements in forest productivity can be expected even in highly degraded forests. Degradation due to community management has been less expected because CFs are bounded by requirements for forest protection and sustainable use under the *Forest Act 1993* and *Forest Regulation 1995*. Moreover, CF management is highly connected to the livelihood options of local communities (Sunderlin *et al.* 2005) and discussions with local communities in the field indicated their need to manage forests well both for themselves and also out of respect for their ancestors.

The *Forest Act 1993* of Nepal allows local communities to use forest resources for their basic forest product needs (GoN 1993). However, CFUGs use forest products differently according to their socioeconomic situations and available supply sources (Adhikari *et al.* 2004). If extraction exceeds recruitment, that results in lower stocking rates. Therefore it can be said that if CFUGs change the extraction rate of trees in CFs, they can change the stocking rates of certain size trees. Under the REDD+ project, communities have changed a range of silvicultural activities including harvesting practices, thinning and plantation activities. These changed activities could be one reason for the observed change in the stocking rate of different sized trees in the forests. Communities carried out these operations mainly to improve forest conditions while fulfilling their subsistence needs for forest products during the inception phase of CFs in Nepal (Gilmour & Nurse 1991). However, this aim was gradually expanded to address the economic development of communities through active forest management practices aimed at increasing the quantity of high value timber trees in forests (Acharya 2002; Acharya 2003) and carbon stock increment benefits from the REDD+ projects.

Different vegetation types in CFs show different distribution patterns of trees by size. This is because the germination and growth characteristics of particular vegetation types affect the stocking rates of each size of plants in forests (Troup 1921). In the 2010, regeneration was higher in *S. robusta* dominated forests followed by mixed broadleaf, *Schima-Castanopsis*, *Pine* and *Rhododendron-Quercus* forests, respectively. These species have different seed production and regeneration capacity. Some need specific seed treatment to increase germination; for example, *Rhododendron-Quercus* and *Pine* need specific seed treatment to increase the germination percentage. As noted in silviculture books, climatic factors such as rainfall and sunlight affect regeneration and the canopy cover of forest can inhibit germination by limiting the amount of sunlight and rainfall at ground level (Troup 1921; Jackson 1994). A study conducted in *S. robusta* forest in Nepal found that an optimum spacing and canopy cover is needed for germination , with both highly dense and sparse forests having lower recruitment rates (Sapkota *et al.* 2009). Additionally, community interests may also affect the recruitment of certain species; regeneration of broadleaf species *Alnus* and *Schima, Lyonia* spp were promoted in in *Pine* dominated forests where community preference favoured a broadleaf forest type (Timsina 2005). However, this study found that community aims have been altered by including REDD+.

Stocking rates of saplings and trees in CFs can be affected by harvesting and thinning practices of communities (Nyland 1996). According to the communities, most of the CFUGs are doing selective harvesting for timber and thinning to create better growth environments in the forests; these activities may affect the stocking rates of saplings and trees. If numbers harvested during those activities exceed recruitment, stocking rates would be decline whereas the opposite will occur if they harvest less. This may affect the reverse-J shaped distribution patterns of vegetation which may then skew the potential yield of forest products. Communities might be protecting timber species such as *S. robusta*, *Pine* and *Schima-Castanopsis* species in the study areas but conducting no regular management activities in *Rhododendron-Quercus* forests which are not useful for timber. Moreover, *S. robusta* is a restricted species to harvest (GoN 2000) which may be one reason to increase the stocking rate of larger tree sizes.

For the REDD+ project, communities may operate thinning activities and remove unhealthy or bent trees and thin dense regeneration to create a better environment for the remaining good condition trees as suggested in the literature (Smith *et al.* 1997). This is identified as a common forestry operation of communities which may be responsible for the decrease in the stocking rate of new recruits in 2013 compared to 2010. Stocking rates of new recruits had declined to a greater extent in *S. robusta* forests compared to those in *Rhododendron-Quercus* forests which had either marginally decreased or slightly increased. Possible reason for these differences could be that a good seed year for *S. robusta* occurs at three to five year intervals (Champion and Seth, 1968 cited in Rautiainen *et al.* 1997) and there is no new regeneration in forests during this interval. Similarly, dieback could be affecting *S. robusta* regeneration. Repeated dieback over 10–25 years, with inhibition of shoot growth and mortality of newly germinated seedlings, has been recorded for *S.*

robusta (Rautiainen 1995). Evidence of dieback differs with site (soil, climate, topography) and disturbance factors (forest fire, grazing). However, under community forest management, forest situations have improved with positive results for regeneration stocks. On the other hand, the occurrence of forest fire is higher in low land terai that also affects regeneration (Gentle 1997). However, with better management of communities, fire intensity and damages impacts were reduced, helping to improve regeneration patterns. With the possible incentive mechanism of REDD+, CFUGs may have started to increase the stocking rates of larger trees to increase carbon stock in their forests and therefore saplings and trees were found to be increasing in CFs. Communities are carrying out thinning activities in a cycle which differs from that in other vegetation and may have changed stocking rates. Stocking rates of saplings was slightly decreased in sparse forests in *Schima-Castanopsis* and *Rhododendron-Quercus* dominated stands. This could be due to growth characteristics of *Schima-Castanopsis* which is fast growing (Paudel 2005); hence, sapling size may convert into tree sizes in few years. On the other hand, communities may harvest more smaller trees for a range of purposes, such as making handles for agriculture equipment, rafters for cattle shed or building houses, causing a reduction in the stocking rates of sapling. Changes in the stocking rates of trees, the main carbon pool stock in forests, were positive in all dominant vegetation types. This shows that CFUGs are able to increase the number of larger trees in forests for carbon benefit.

The overall distribution of different trees sizes in CFs is good indicating their capacity to continue to produce additional biomass carbon for the long term under the REDD+ project. As found in Pandey (2007), the results indicated that the present forest management practice of communities may be promoting timber trees and fast growing species for REDD+ carbon benefits which may undermine the global aim of biodiversity conservation (CBD 1992). Most of the CFUGs have income generating interests in their forest conservation (Subedi 2006), therefore there are possibilities to reduce the diversity and habitat condition of endangered plants and wildlife, and provide less support for maintaining ecosystem services for carbon benefit. As suggested by Angelsen (2012), safeguarding these services is important in REDD+ projects and there is need to consider protection and to incentivise communities to ensure these co-benefits are realised while designing and implementing REDD+ projects in CFs.

8.4. Changes in carbon stock in CFs under REDD+ mechanism

CFUGs were found to be contributing to the conservation of carbon stocks and showing capacity to further increase carbon stocks in forests under REDD+ projects. However, each CF had different capacity to contribute carbon in delivering sequestration outcomes. As also reported by Turner *et al.* (1995) and Litton *et al.* (2003), this study found a higher carbon sequestration capacity in trees than sapling and other pools (Appendix F). Therefore, a forest having a higher stocking rate of trees can store higher carbon stocks than less stocking. However, saplings have the potential to grow vigorously whereas trees may soon mature and stop growing. The sigmoidal growth pattern of trees indicates the higher increment potential of saplings than old trees (Birch 1999); therefore, a forest with a large number of saplings could have more carbon benefits in the long run. Among trees, size and vegetation characteristics affect biomass carbon because biomass carbon is a function of the height and diameter of trees and the specific gravity of wood (Chave *et al.* 2005). A higher stocking rate of larger trees was found in *S. robusta* forests, indicating their higher carbon stock than other forests in the year 2010. Wood specific gravity of *Shorea robusta* species is higher than that of *Pine* tree species (MPFS 1988).

Tree species in forests are different by altitudinal location i.e. *S. robusta* and mixed broadleaf forests are located at lower altitudes, *Schima-Castanopsis* and *Pine* forest are at middle altitudes and *Rhododendron-Quercus* in higher altitude areas (Manandhar 2002; Vetaas & Grytnes 2002).The study found that the forests at lower and higher altitude areas have higher carbon stocks than those at middle altitudes. As in a study conducted in the forests of Hawaii with an altitudinal range of 914 to 2,438 m asl (Aplet & Vitousek 1994), this study found an increase in biomass as altitude decreased in all forests types with the exception of *Rhododendron-Quercus* forests. *Rhododendron-Quercus* forests were located at higher altitude areas but had higher quantities of carbon stock than *Pine* and *Schima-Castanopsis* middle altitude forests, indicating that many factors before and after the inception of CFs play roles (which have been discussed in next sub-section). The lower carbon stock in middle altitude forests was probably due to higher human pressure on forest resources; these forests were probably highly degraded before CF management as has been contended elsewhere (Gilmour *et al.* 1989; Gilmour *et al.* 2004). Although people living at higher colder altitudes need more fuel wood energy (KC *et al.* 2011), the populations are comparatively small compared to those in middle and lower altitude areas (CBS 2011b) . Therefore, total demand is less in high altitude areas. According to the guidelines for community forestry in Nepal (CFD/DoF 2009), a CFUG can extract a certain proportion of the total increment of forest products. However, they reduced extraction for REDD+ project. In sparse plots, illegal extraction of forest products occurred from outsiders before CFs was established; this has been reduced now through mechanisms which guard forests. As degraded forests have lower site productivity (Fox 2000), sparse forests are comparatively degraded and had less carbon increases.

While comparing results from closely-related studies (similar species, climate and altitudinal ranges), this study generated slightly different results (Table 8.1). Both *S. robusta* forests and mixed broadleaf forests are closely related to the tropical moist forests (Asia continent) category (IPCC 2006) and forest types of Bihar and Uttar Pradesh (Haripriya 2000). Estimated carbon stocks in both these forests (in year 2010) was within the range given in IPCC (2006), higher than the estimation of FAO (2010b) for South and Southeast Asian forests and the estimation of Chhabra *et al.* (2002) and Kaul *et al.* (2009) for Bihar forests. Similarly, *Schima-Castanopsis* forests of the study areas are closely related to the sub-tropical humid forests (Asia continent) category of IPCC (2006) and forests of Himanchal Pradesh (Chhabra *et al.* 2002; Kaul *et al.* 2009). By comparison, the carbon stock estimate for *Schima-Castanopsis* forests was within the range given in IPCC (2006), higher than the estimation of FAO (2010b), and less than the estimation of Chhabra *et al.* (2002) and Kaul *et al.* (2009) for Himanchal forests. In the case of *Pine* forests and *Rhododendron-Quercus* forests of the study areas, these were similar to the temperate forests (Asia continent) in the IPCC (2006) category and forests of Himanchal Pradesh in Chhabra *et al.* (2002) and Kaul *et al.* (2009) categories.

Carbon stock estimated in Pine forests and *Rhododendron-Quercus* forests was within the range given in IPCC (2006), higher than the estimation of FAO (2010b) and less than the estimation of both Chhabra *et al.* (2002) and Kaul *et al.* (2009).

Estimated carbon stocks in all categories of forests in the study were within the given range of IPCC (2006) categories and less than the estimation of both Chhabra *et al.* (2002) and Kaul *et al.* (2009) for Himanchal and Uttar Pradesh forests except in *Shorea robusta* forests. A possible reason behind this exception could be better condition of the forests before the inception of community forestry (Nagendra 2002) which has then kept improving under community management (Acharya 2002). The situation of *Schima-Castanopsis*, *Pine* and *Rhododendron-Quercus* forests were the opposite where forests were highly degraded when CFs was initiated in the early 1970s (Gilmour & Fisher 1991; Gautam *et al.* 2003).

On average, the stock of carbon in forests with REDD+ projects is increasing in CFs which agrees with the common pool theory that collective action and shared goal of communities can improved common pool resources (Ostrom 1990). As the success of CFs is dependent on various factors (Acharya 2002), REDD+ project tends to increase different carbon stock in CFs with various characteristics.. Higher increases in carbon stocks are found in CFs where the dominant vegetation is *Pine, Schima-Castanopsis* and mixed broadleaf which have fast to moderate growth characteristics. The increment is comparatively less in the CFs with slow growing species *Rhododendron-Quercus* (Smith *et al.* 1997). While compiling the sampling inventory, we also documented the growth stage of the forests. Most of these forests were young and had not reached maturity. Therefore, the CAI of the forests are higher. We estimated 5.0 MgC/ha/yr for *S. robusta* forest, 5.8 MgC/ha/yr for mixed broadleaf forests, 6.2 for *Schima-Castanopsis* forests which is higher than the value of 2.0 MgC/ha/yr given in IPCC (2006) for closely related forests in tropical and sub-tropical forest categories. Similarly, our estimate for *Pine* forests was 6.4 MgC/ha/yr which was higher than the value given in IPCC (2006) for temperate forests (4 MgC/ha/yr) but the estimate was lower in the case of *Rhododendron-Quercus* forests (2.2 MgC/ha/yr).

Possible key reasons for such differences include the conservation oriented forest management activities of local communities (Pagdee *et al.* 2006); the availability of alternative sources of forest products; the growth characteristics of the vegetation (i.e. fast, moderate or slow growing); as well as the productivity of the study sites (Smith *et al.* 1997). Moreover, the REDD+ pilot project has facilitated training and awareness rasing activities, promoting alternative energy (e.g. improved low fire wood consuming cooking stock and biogas), planting and silviculture activities and changing forest product use practices and has improved forest management activities toward carbon benefits. According to the communities, extraction of forest products is a key driver reducing carbon stock but reduction in forest products harvest is only possible if there are alternative sources. Therefore, the development and promotion of appropriate alternative energy sources could be an important intervention in *Rhododendron-Quescus* forests where carbon stock increments are lower. Based on increased carbon stock, *Schima-Castanopsis* and *Pine* forests can deliver more benefits and these forests may also receive greater emphasis for REDD+ carbon benefits.

Table 8.1 Comparison between our estimates and other estimates for closely related forests for carbon stock (MgC/ha)

This study (Litter included)		**IPCC (2006) (Litter excluded)**		**Biomass in states forests* were estimated by Chhabra *et al.* (2002) (Litter excluded)**		**Biomass in states forests* were estimated by Kaul *et al.* (2009) (Litter excluded)**		**FAO (2010b) (Litter excluded)**	
Forest types	***Biomass Carbon (MgC/ha)***	***Closely related classification***	***Biomass Carbon (MgC/ha)***	***Closely related classification***	***Biomass Carbon (MgC/ha)***	***Closely related classification***	***Biomass Carbon (MgC/ha)***	***Closely related classification***	***Biomass Carbon (MgC/ha)***
Shorea robusta	121	Tropical moist deciduous forests (Asia continental)	107 (6-334)	Bihar (*Shorea robusta* and *Acacia species)*	111	Bihar (*Shorea robusta* and *Acacia species*)	53.75	Average of 18 countries including Nepal (South and Southeast Asia category)	85.6
Mixed broadleaf	110			Uttar Pradesh (*Shorea robusta*, Mixed broad leaved)	245		174.90		
Schima-Castanopsis	88	Sub-tropical humid forests (Asia continental)	107 (6-334)	Himanchal (hard wood mixed with conifers, Pines)	136	Himanchal (hard wood mixed with conifers, Pines)	194.95		
Pine forest	91	Temperate continental forest (Asia)	73 (12-196)	Himanchal (hard wood mixed with conifers, Pines)	136	Himanchal (hard wood mixed with conifers, Pines)	194.95		
Rhododendron-Quercus	102								

Note: * Species available in the state is mentioned by Haripriya (2000)

8.5. Potential carbon growth in CFs

CFUGs are found contributing to increased carbon stock in forests under REDD+ pilot initiatives; however, each forest could have a limit to its capacity to produce carbon stock. The maximum capacity of a forest to gain volume in an undisturbed natural condition is called "theoretical maximum yield in forests" (Rautiainen 1995) which is the maximum technical potential to grow. An undisturbed forest is an ideal state where only natural factors are active (Rautiainen 1995). It can be assumed that if community extraction of forest resources and management activities were not allowed in the CFs of the study areas, those forests would also follow natural growth patterns by attaining theoretical maximum carbon stock with time. In other way it can be said that if communities stop their activities and fully protect a forest, it could attain theoretical maximum growth. For designing a REDD+ project activities, knowledge about potential carbon growth (i.e. gaps between theoretical maximum carbon stock in forests and actual carbon stock in CFs) would be useful.

This study showed high potential of CFs to increase carbon stock under the REDD+ mechanism. While comparing carbon stock in *S. robusta* CFs (both dense canopy and sparse canopy) and undisturbed forests (i.e. theoretical maximum) by the age of forest stands, a clear gap has been identified. This gap is higher in sparse canopy forests than dense category forests (Table 8.2). This is supported by a study conducted in spruce forests which also found that dense canopy forests have higher biomass than sparse forests types (Michalek *et al.* 2000) so it is obvious that sparse canopy forests have high potential to grow with REDD+ intervention. Vegetation forms a sigmoidal curve if yield data is placed in y-axis and age data in x-axis ranging from zero to maximum age (Birch 1999; Weiner & Thomas 2001). This is because tree growth generally follows a pattern that is slower at young age, gradually higher after certain age and slower at older age (Weiner & Thomas 2001). A similar pattern of sigmoidal curves has been estimated in both dense and sparse CFs in this study (Chapter 5) however gaps differ with the age classes of forests. In both sparse and dense canopy CFs, estimated gaps were less in young stands than in old age stands. This shows young forests could have less potential to gain net additional carbon stock than older stands in which the gaps were higher. The majority of forests were found with the dominant age of trees in the 30 to 49 year category (Table 8.3) where the potential to increase was 230.26 mg/ha (in dense stand) to 441.33 mg/ha (sparse stand) in *S. robusta* forests. In the case of other vegetation types, there is limited knowledge about the theoretical maximum carbon stock by age of mix broadleaf forests, *Schima-Castanopsis* forests, *Pine* forests and *Rhododendron-Quercus* forests; therefore, this study did not perform detailed comparisons between the theoretical maximum and actual carbon stock in CFs for these forest types. It is inappropriate to use the theoretical maximum value of *S. robusta* for those vegetation types because the growth characteristics are completely different (Jackson 1994). However considering the same policy provisions of CFs and community practices with similar intervention strategies in all CFs of the country (Acharya 2002), it can be assumed that CFs with those vegetation types might also have similar gaps between the theoretical maximum carbon stock and therefore have similar potential capacity to grow carbon stock. CFs dominated by young age stands have comparatively smaller gaps between the theoretical maximum carbon stock of that age and older aged stands (Table 8.2) which indicates there are missing old age trees in CFs. There could be two reasons: either communities are extracting larger and old age trees legally or illegally or the number of old age trees were less in the forests when the communities started CFs (Gilmour & Fisher 1991). However, CFs may have reduced stocks of old and large trees because they are allowed to harvest some forest products while ensuring forest condition is maintained (CFD/DoF 2009).

Table 8.2 Theoretical maximum carbon stocks by years in CF and undisturbed *S. robusta* forests

S. robusta forests	Present carbon stock (by Age)				Theoretical carbon stock (by Age)				Potential to increase (by Age)			
	10yr	30 yr	50 yr	70 yr	10 yr	30 yr	50 yr	70 yr	10 yr	30 yr	50 yr	70 yr
Dense	34.82	125.76	183.74	205.50	88.83	356.02	588.35	760.55	54.01	230.26	404.61	555.05
Sparse	19.59	95.48	147.02	167.37					69.24	260.54	441.33	595.18

Table 8.3 Age category of CFs by dominant vegetation types

Dominant vegetation type	CFs numbers by age of the dominant vegetation					
	10-19 yr	20-29 yr	30-39 yr	40-49 yr	50-59 yr	60-69 yr
S.robusta mixed broadleaf	0	7	11	15	4	0
Schima-Castanopsis	0	14	13	11	5	0
Pine	0	2	9	5	0	0
Rhododendron-Quercus	0	2	5	1	1	0

As noted, communities are protecting forests, carrying out plantings and sustainably harvesting forest products, all of which could change the natural patterns of growth in CFs (Springate-Baginski *et al.* 2003). However, even if communities do the same activities in forests, site quality differences may affect biomass growth (Daniel *et al.* 1979; Smith *et al.* 1997). CF provision was not a priority during the inception phase of CF in Terai areas of Nepal (MPFS 1988); however, the government brought in a separate policy to engage local people in the management of degraded forests and started the handover in 2000 (GoN 2000). Therefore, it is obvious that CFs were initiated to protect degraded forests and so biomass carbon by age was less in CFs than in undisturbed *S. robusta* forests. After protection and management activities of CFUGs, a gradual improvement in forests has occurred (Pagdee *et al.* 2006; MFSC 2013) and reversed the condition of degraded forests (Singh & Chapagain 2006). Theoretical maximum carbon stock values used in this study were taken from the yield table developed for *S. robusta* forests of Nepal (Rautiainen 1995), developed using data from almost uniform forests with 20% other vegetation mix in Terai. The data used for the yield table was collected from sample plots located in Makwanpur, Rupandehi, Kaski, Bara, Nawalparasi, Chitwan sites. These sites represent diverse locations of *S. robusta* forests matching the Kayerkhola watershed and Ludikhola watershed sites of this study in topographical and climatic aspects (Rautiainen 1995). While this is the best suited data for this study, the yield table of undisturbed forests was developed for site quality I and II, the highest ranking sites based on production capacity (Rautiainen 1995). The sites covered in this study were not uniform and likely to be more variable in terms of their productive capacity. However, if the forests were left without human disturbances, both dense and sparse forests of study areas could potentially achieve similar amounts of carbon stock as is found in undisturbed forests.

Appropriate open space available in forests provides opportunity for regeneration for some tree species. This is because sparser forests could have higher levels of erosion of productive soils, while denser forests might experience higher levels of competition among trees for sunlight and nutrients that affect growth rates (Smith *et al.* 1997). As sparse forest allows rainfall to reach the forest floor it has higher soil erosion potential (Rogers & Schumm 1991) that may reduce soil productity. With more soil erosion and lower forest productivity, sparse forest could have less biomass carbon growth potential by age than dense one. However this is improving with community efforts.

Increased rates of carbon yield may affect the optimum rotation age of a particular forest. In forestry, biological rotation (Huang & Kronrad 2001) and economical rotation (Gardiner & Quine 2000) are in practice. The biological rotation age is the time when each stand reaches a maximum mean annual increment i.e. highest biological productivity where MAI and CAI coincide (Tanvir *et al.* 2002). In economic rotation, the maximum net present value of a forest is considered to decide the rotation age of the forest. However, in the case of carbon sequestration benefits, rotation age could be different than either of these. Higher carbon sequestration could be possible with an extension of the rotation age beyond the optimum economical and biological rotations of forests because a longer rotation age is better for carbon sequestration (Liski *et al.* 2001; Foley 2009). The biological rotation age for biomass carbon yield in dense canopy CF was found to be younger than that of sparse canopy

CFs. As growth is dependent on optimum space available on the forests floor, disturbance, site quality, topographic factors, edaphic factors and climatic factors (Khanna 2004), forests dominated by the same vegetation type have almost similar topography, climate and soil types. Silviculture operations (i.e. thinning - removing the less healthy trees from dense stands and Singling - keeping single healthy sprout from multiple coppices from a stump) may help to reduce completion and create a favourable growth environment (Khanna 2004) to promote growth into old age, thereby helping to expand the biological rotation age in dense stands. This is supported by a research carried out for Douglas-fir which found that dense forests have a cumulative MAI curve which is greater at an early age than that of sparse forests (Curtis 1995), meaning that optimal spacing is an important factor in obtaining maximum sustained yield (MSY). Therefore optimum stocking rates of trees in forest stands is expected to increase carbon stock and silviculture operation might be helpful for it. Similarly sparse CFs reach MSY at an age similar to that of undisturbed forests, however the quantity of carbon is less than the theoretical maximum level and needs to be carefully managed to ensure its protection from biomass reduction factors.

In the case of dominant mixed broadleaf forests, *Schima-Castanopsis, Pine and Rhododendron-Quercus* forests, there is only limited evidence in the literature for the estimation of theoretical maximum biomass carbon stock levels under undisturbed natural conditions. There is evidence from the available literature for specific ages; for example above ground biomass of *Pinus roxburghii* plantation aged 9 years (Applegate *et al.* 1988a; Applegate *et al.* 1988b) and 10 years (Mohns *et al.* 1989) but this does not give growth patterns across the range of ages. Therefore, this study compared the 90th and 10th percentiles of carbon stock values estimated in forests and found huge potential to increase carbon stock if the 90th percentile carbon stock value is taken as the potential carbon stock in CFs. This study could not locate age-specific carbon stock measurements in CFs to enable the analysis if age-wise gaps. However, it indicates carbon stock gaps in forests and differences within a vegetation type. These differences are mainly due to the size and age of trees in stands because dense canopy cover with young or small trees store less carbon than dense canopy cover with old or large trees (Nowak & Crane 2002; Nowak *et al.* 2002). This shows potential to increase carbon stock with REDD+ interventions in both dense and sparse canopy CFs.

Although, there is potential to increase carbon stock in CFs, it may not be possible to attain the theoretical maximum level. This is because the fundamental principle of CF is to enable local communities to participate in the management of forests and sustainable supply of forest resources to fulfil subsistence forest product needs (Adhikari *et al.* 2007) therefore it may not be possible to fully control the extraction of forest resources and to enforce strict protection rules in CFs. Rural communities are highly depended on CFs for their forest product needs (Adhikari *et al.* 2004). In designing and implementing REDD+ projects, proper mechanisms must be in place to ensure that the socio-economic benefits to communities are safeguarded as agreed internationally (UNFCCC 2011); such mechanisms should ensure the supply of forest products to fulfil the needs of forest users by either developing sustainable forest use practices or by providing alternative means for fuel wood energy, promoting plantations on private uncultivated lands and the supply of grass and fodder. If the REDD+ project does not consider these aspects, communities may suffer and pressure on other forests outside project areas may increase with increased extraction of forest resources leading to increased leakage in terms of carbon sequestration. Leakage due to displacement of forest resource extraction from REDD+ to non-REDD+ forests (Hetsch & Chang 2010) does not contribute to the overall mitigation of climate changes. On the other hand, only a limited number of tree species are fast growing and capable of higher contributions to carbon sequestration compared to slower growing species. Communities may prefer faster growing species under carbon oriented management programs, which may not be beneficial from a biodiversity point of view. Because limited species forests are less likely to provide habitat for various flora and fauna, such programs may contradict the aims of agreed biodiversity conventions (CBD 1992).

8.6. Key factors affecting carbon stock in CFs

The existing literature indicates that biophysical and socio-economic factors influence forest areas (Geist & Lambin 2002; Lambin *et al.* 2001; Nagendra 2007; Yang *et al.* 2006). Among these factors, species domination in a CF, elevation of forests, proximity of forests to roads and settlements, the average age of the dominant trees of forests stand, per capita forests area, the size of household level agricultural land holdings, average numbers of livestock, the proportion of households using biogas and the proportion using petroleum energy, livestock grazing, caste heterogeneity, the quantity of biomass (timber and firewood) extraction, the quantity of grass collected, the quantity of fodder collected and the quantity of litter collected in CFs are indicated as major factors for carbon stock differences. As CF is completely different in terms of forest management objectives, management practices and outcomes to other government and private forestry models (FAO 2011), these factors may not play similar roles in CFs.

The dominant tree species in a forest is one of the key factors that affect carbon stock in CFs. As found in the literature, differences in carbon stock are mainly due to the growth characteristics of vegetation in forests (Silver *et al.* 2004). CFs with dominant *Pine* vegetation had higher carbon stock increment rates in this study due to fast growing nature of the species (Jackson 1994; Khanna 2004). Similarly, the wood density of vegetation types in the study CFs differ (MPFS 1988) and wood density affects the quantity of carbon stock in the forests (Baker *et al.* 2004). Although, this is mostly due to natural characteristics, CFUGs can influence the composition of forests through silvicultural practices (Pandey 2007) also changing carbon stocks. Therefore policy makers may need to consider species composition while designing REDD+ project activities. Different stocking rates of trees in forests also affect carbon stock differences in CFs. Across all vegetation types, CFs had higher carbon stocks in dense canopy forests (i.e. high stocking rates of trees) storing higher amounts of carbon stock than sparse canopy forests. This is supported by a study conducted in urban forests in USA which found that large diameter and higher numbers of trees per unit area of forests contribute large quantities of carbon sequestration in forests (Nowak & Crane 2002). Degraded condition in forests at the starting time of CF also affects carbon stocks in CFs. The level of degradation was worse in the mid-hills of Nepal when CFUGs were formulated and initiated to protect degraded forests (Gilmour *et al.* 1989; Acharya 2002 therefore these forests had fewer larger tree than other CFs in the study. Forest elevation is another possible factor affecting carbon stock in CFs. According to the literature (Gégout *et al.* 2005), climatic variables and soil properties in forests differ with elevation gradients. These climatic variables affect the distribution and growth rate of each species (Khanna, 2004) and therefore affect carbon stocks. A study found that biomass amount was higher in a warm wet climate compared to cool dry types (Aplet & Vitousek 1994) which may indicate lower altitude warm weather could support higher biomass carbon in the study sites. Lower altitude tropical forests can also store higher carbon stock than temperate forests (Malhi *et al.* 1999; Gibbs *et al.* 2007). This study found similar results in the case of *S. robusta* mixed broadleaf forests which store higher carbon stock than other forests while *Schima-Castanopis* and *Pine* forests (sub-tropical forests) had lower carbon stock than *Rhododendron-Quercus* forests (lower temperate). There is, however, a seemingly unusual outcome in the higher biomass stock in sub-tropical forests (middle altitude area) possibly due to the high pressure on forest resources in middle altitudes resulting in higher levels of degradation prior to the establishment of CFs (Gilmour *et al.* 2004; Gilmour *et al.* 1989). In these areas, people were forest dependent and forests were treated as open access resources before the inception of the CF model (Gilmour 1990). Similarly, there was an unequal distribution of the population during the 1980s (i.e. before CF) when 60% people were living in hill areas and the major population concentration was in the middle altitudes (Shrestha & Conway 1985). This reflects the existing CF situation with forests located in middle altitude areas tending to have less carbon compared to those at higher and lower altitudes and so having higher potential to increase with REDD+ projects.

The proximity of forests to road-heads and settlements could be a cause of decreasing biomass carbon because people could have easy access to extract forest resources from the forests. A study conducted in Uttarakhand Himalaya found higher forest degradation in forests accessible from roads (Singh & Singh 1997); however, these were government forests where outsiders might have increased the pressure on forest resource use. CF is different as local communities take responsibility and guard against illegal harvesting. On the other hand, road access can provide opportunities to generate income, particularly for rural poor communities, by connecting them to market centres (Jacoby 2000; Banerjee *et al.* 2012;) which may indirectly help to protect forests. If people have higher incomes, they can afford alternative energy source such as biogas (Gewali & Bhandari 2005), which helps to increase carbon stock in CFs. Therefore, proximity from road head may not have effect on carbon stock in CFs as was indicated in this study with no clear pattern of carbon stock difference found. Similarly, there were no effects on CF carbon stocks due to the proximity of forests to settlements found in this study. This is because communities have full ownership and the shared aim to protect forests in CF systems and they contribute to improving forests (Ostrom 1990; Ostrom *et al.* 1994). Similarly, CFUGs do only selective logging (i.e. logging only those trees which are an exploitable size from improved forest management perspectives) and aim to improve forest status in all areas (Yadav *et al.* 2003). This was the opposite in a study carried out in Myanmar that found that a nearby village extracted more forest products from closely located forest areas, reducing biomass (Mon *et al.* 2012), where ownership was not given to the local people who were dependent on the forest resources. Therefore proximity to settlements may not affect carbon stocks in CFs. According to forest policies (GoN 1993), CF is a forest management system where traditional local users get forest management responsibilities and manage forests in a systematic way. Since, they have ownership of the forest resources, communities can further improve forests for REDD+ carbon benefits through plantation and reducing extraction from CFs in forest areas.

This study indicates that the age of trees in a stand is another factor affecting carbon stock in CFs. A higher quantity of carbon stock was maintained in older aged forests in all vegetation types in study CFs; other studies (Luyssaert *et al*. 2008; Keith *et al*. 2009) also report that old age forests have higher carbon stock than younger one. As carbon stock changes were greater in younger forests and most CFs were not old, there was high potential to increase carbon stock. Increased rates could be different in CFs due to the age of trees in forests because trees form sigmoidal growth patterns by age (Weiner & Thomas 2001) and a CF could fall at certain stage on the curve (e.g. juvenile, higher and slow growth). If REDD+ incentive mechanisms only consider the carbon increment, a CFUG that is doing better in terms of its conservation activities and had well stocked mature forests could receive less payment than a CFUG which had extracted all the aged trees and had only young trees. This situations would disappoint the people who were doing a good conservation job before the implementation of REDD+ projects. It might not be ethical to award such a situation while neglecting the work of others. Therefore, the REDD+ in CF should create a payment mechanism that considers these aspects.

The size of forest allocations (per capita forests) in CFs may affect the carbon stock. It was found in most of the CFs that the larger the per capita forest had higher carbon stock. This was also supported by findings reported in the literature (Agrawal & Goyal 2001; Nagendra *et al.* 2005). Communities can extract a certain proportion of increased wood biomass that does not reduce existing carbon quantity in forests. However, if people extracted similar amounts of forest products from large and small CFs, larger forests can continue to increase carbon stock more than smaller forests. This was especially the case when alternative sources of forest resources were limited and communities' only option was to use CFs. However, there is no indication of effect of forest size in high *Rhododendron-Quercus* forests in this study where people have comparatively larger areas of non-arable land growing trees and supplying forest resources compared to lower altitudes (Maltsoglou & Taniguchi 2004). Similarly, CFs with larger per capita forests can build higher carbon stock without compromising forest product benefits in REDD+.

As agricultural land provides food and other income sources to rural people (Adhikari *et al.* 2004) and also produces forest products, CFs with larger average areas per household of agricultural land can have higher carbon stock. However, in the Terai, (*S.robusta* and broad leaf forests areas), agricultural land is highly productive (Maltsoglou & Taniguchi 2004) and productive land is not used to grow trees as it is in higher altitude areas. With REDD+ project activities, the growth of biomass carbon in forests was higher in all CFs associated with larger areas of agricultural land as was shown in Table 6.6; this is because larger agricultural land holding households in a CF are able to access additional supplies of forest resources (Chhetri 2005). For example, where CFUG members have larger areas of non-irrigated land, they plant grasses and trees to meet the household demand for forest products; this was mostly evident in the middle and high altitude areas.

The proportion of biogas using households may affect the carbon stock in CFs. However, biogas is more effective in lower altitude warmer areas and only applicable if the household has 2 to 3 cattle to operate the biogas plant (Singh & Sooch 2004; WECS 2010); only the rich members of *S.robusta*-mixed broadleaf CFUGs were adopting biogas. Biogas energy can fulfil household energy needs and reduce the use of firewood as mentioned in other studies (Pokharel & Chandrashekar 1994; Shrestha 2005); therefore, if a higher proportion of CFUGs are using biogas, this may result in higher carbon stock in the forests. In terms of feasibility, the REDD+ project could facilitate the installation of biogas plants by providing subsidies, technical support and linking with government subsidy programmes for alternative energy adoption (GoN 2009). Some households in CFUGs had installed biogas plants but were using firewood for cooking large quantity food items including livestock feeds and heating house during winter. This is because communities found biogas stoves less effective for both cooking and heating. This indicates that biogas may possibly contribute to a reduction in firewood consumption but there is a need for technology development particularly in the design of a more effective biogas stove for cooking. As the average per capita income of Nepalese people is less than $2 a day (CBS 2011a) and most forest dependent people are poor, they may not be able to afford the cost of plant construction or to buy cattle to operate it. Upfront financial support would facilitate biogas adoption. Without this, leakage due to fuel-wood extraction from REDD+ CFs to fulfil household energy demand may require REDD+ projects to include restrictions to control this.

Proportions of petroleum energy (e.g. kerosene) or LP gas using households in CFUGs is another factor affecting carbon stock. These energy sources are used for cooking in the study areas. The study found that if the proportion of petroleum energy using households in a CFUG was high, it had a higher increment of carbon stock than lower ones. This shows the contribution of alternative energy for increasing biomass carbon in CFs. However, fossil fuel is not a major source of energy, contributing less than 12% energy (World Bank 2011c) to total energy demand of Nepal. In general, LP gas was used by rich families mostly in city areas rather than rural areas. However, burning LP gas and kerosene stoves also contribute to greenhouse gas emissions (Bhattacharya & Abdul Salam 2002) and it would be advantageous to promote biogas, electricity and solar energy as alternatives to fuel-wood energy rather than these energy sources in the REDD+ project.

The quantity of tree and fuel wood extracted is another key factor affecting carbon stock in CFs. Similar to the finding that a higher biomass extraction in forests reduces biomass carbon stock in forests (Manhas *et al.* 2006), this study found that communities which extract higher biomass quantity (i.e. timber and firewood) from a CF had less biomass carbon stock. In CFs, communities can harvest an allowable quantity of timber and fuel wood as prescribed in the CF guidelines 2009 (CFD/DoF 2009) and forest inventory guideline 2002 (CFD/DoF 2002). However, after the REDD+ project activities, communities had reduced biomass extraction and were able to increase carbon stock in forests most probably higher than in non-project CFUGs. Communities are fulfilling their biomass product needs by extracting in a conservative way where the extraction quantity is less than the growth increment of a forest. As noted, for safeguarding the crucial needs of local communities and reducing possible leakage, communities should follow sustainable use practices of forest products and adopt alternative energy source of fuel wood in REDD+ project areas. The use of improved cooking stoves (ICS) is a cheaper option to reduce fuel wood use in CFGs. ICS can reduce wood consumption by 30–40% more than traditional stoves (Dhakal & Raut 2010). Therefore REDD+ project need to consider these aspects while planning for generating carbon benefits in CFs.

This study found no effect of caste heterogeneity in carbon stock changes in CFs. As stated in the literature, heterogeneous groups may have different interests and therefore have problems reaching a consensus decision on better forest management practices leading to the "tragedy of unmanaged common resources" (Hardin 1968). However, this study found the opposite, with heterogeneous groups showing better understanding, mutual trust and collective action, and doing better in terms of forest management defiance of "common pool theory" (Gautam *et al.* 2003; Poteete & Ostrom 2004). Carbon stocks have been maintained in both heterogeneous and non-heterogeneous CFUGs. Since, CFUGs have different forest product dependency and economic situations (Adhikari *et al.* 2004), the REDD+ decisions may create problems for highly forest dependent members of the community. As per economic transformation theory (Breisinger & Diao 2008), communities may need to change all economic means such as energy use, construction material, livestock and agriculture practices for new mechanism of REDD+ which may have negative consequences to them. Therefore it is expected in the REDD+ project will provide alternatives or compensation for them to ensure the project's success.

Climate change itself can have some effects on carbon growth but there is limited research and information on the impact of climate change on the carbon sequestration potential of forests in Nepal. However, most of the research in Nepal predicts both the rainfall and temperature will increase (Malla 2009; Shrestha & Aryal 2011). From these likely rainfall and temperature scenarios, it can be said that climate change would have a positive impact on the carbon sequestration capacity of forests (Araújo *et al.* 2005). Moreover, carbon fertilisation due to increased carbon dioxide in the atmosphere would further enhance this capacity (Schimel *et al.* 2001; Schlesinger & Lichter 2001). However, climate change is a long-term phenomenon and this research reports the results from a four year survey; therefore it can be said that there is very little effect of climate change on the results of this study. Based on the results, it can be safely assumed that any increase in carbon is solely because of REDD+ pilot project activities and the changed behaviour of communities.

In a nutshell, the capacities of CFs to increase carbon stock differ. This study has indicated age of stands, dominant species, stocking rates of trees, elevation of forests, size of forests, extraction of trees and fire wood in forests may all influence such differences. These factors are contextual; for example, factors affecting lower altitude *S. robusta* forest may not affect higher altitude *Rhododendron-Quercus* forests. Discussion with communities and observation in the field confirm that communities have successfully changed existing forest resource extraction behaviours and reduced damages. Project interventions, particularly in distributing ICS to reduce fuel wood consumption, plantation support, awareness raising activities, distributed incentives for carbon enhancement focusing on the poor and ethnic communities (ANSAB/ICIMOD/FECOFUN 2013), could play a role in this.

8.7. Trade-off between communities sacrificed benefits and carbon benefits in CFs

Since REDD+ is an incentive-based mechanism to increase the carbon sequestration capacity of forests in developing countries, CFUGs were adding additional costs for the REDD+ projects with expectation of possible monetary benefits. They increased their efforts in forest management activities and reduced forest product benefits for REDD+. CFUGs were carrying out different forest management activities mainly plantation activities, guarding against illegal harvesting, carrying out more fire control activities, operating silviculture activities (Yadav *et al.* 2003) and holding meetings and assemblies for decision making (Agarwal 2009) before REDD+ project activities. According to the communties, they have increased activities which have contributed to increased REDD+ carbon benefit. These activities have an added cost burden for CFUGs; however, the added costs differed for various vegetation dominated CFs. For example, meeting costs were highest in *S. robusta*-mixed broad leaf forests and lowest in *Schima-Castanopsis* forests. Possible reasons for higher costs in a CF may be the number of households involved in a CF and higher frequencies of meetings and other participatory activities. If large numbers of members are organized in a CFUG to manage forests, meeting costs will also be proportionally higher. Participation of all members is expected in CF activities and every member needs to attend assembly and forestry activities voluntarily (CFD/DoF 2009). For good governance in REDD+ CFUGs, the participation of all members is crucial to ensuring the effectiveness of the REDD + mechanism (Cadman & Maraseni 2011) therefore CFUGs have increased the numbers of meetings and discussions for REDD+. CFUGs have also changed existing practices according to the characteristics of particular forests, which is seen in sparse *S. robusta* mixed broadleaf forests and *Schima-Castanopsis* forests where more space is available for planting and communities were doing plantation and guarding forests to stop illegal activities. The cost of security was higher in *S. robusta* mixed broadleaf forest which is a highly valuable timber tree and was facing higher illegal harvesting. Among the CFs of the study, CFs located in terai areas were highly sensitive to forest fires. Communities in these areas were engaged in fire prevention measures by constructing fire lines and fire control activities, as found by Acharya (2002). Similarly, *Pine* forest is also sensitive to forest fire and communities have taken care to prevent forest fire by organizing additional activities after the REDD+ projects, particularly raising awareness about fire damage and preventive measures (ANSAB/ICIMOD/FECOFUN 2013).

After a long period of conservation and management efforts by communities, trees in CFs are maturing and are now ready to sell on local markets (MFSC 2013). In addition to subsistence use, such matured CFUGs can generate a cash income from the sale of timber without detriment to forests. However, CFUGs may go for REDD+ carbon benefits by reducing harvesting quantities. This will increase the level of sacrificed benefits in mature CFs if the objective of forest management has shifted from subsistence use to a mix of subsistence and income generation from selling timber on the local market. It is evident in the study area that communities have reduced these extraction practices to increase carbon stocks in the forests with the expectation that the REDD+ income would be higher than the forgone benefits. However, as noted, sustainability of these carbon-centric practices is yet to be researched. A higher sacrificed timber benefits were found in *Pine* forests followed by *S. robusta* mixed broadleaf forests whereas increased timber benefits were recorded in *Rhododendron-Quercus* forests. According to the communities, *Pine* trees are used in the veneer industries and also considered better for furniture in hill areas. CFUGs were moving towards conversion of vegetation composition from *Pine* (conifer forests) to *Schima-Castanopsis* associated broad leaf forests before the REDD+ project (Timsina 2005). But they may have changed those practices and reduced the quantity of extraction for REDD+.

As mentioned earlier, *S. robusta* timber is comparatively durable and a preferred timber species in Nepal and consequently more valuable. Similarly, firewood of *S. robusta* is also expensive due to its high calorific value (Jackson 1994; Kataki & Konwer 2002). Therefore, total costs become higher in *S. robusta* forests than other forests even if they reduce the quantity harvested under the REDD+. *Rhododendron* and *Quercus* trees were mostly used for firewood, being a less expensive option compared to *S. robusta* trees. On the other hand, a higher cost for reducing benefits from grasses and litter was found in *S. robusta*-mixed broadleaf forests; this was lowest in *Rhododendron-Quercus* forests. Moreover, communities have reduced livestock numbers and are increasing the use of grasses and agricultural residue to feed their livestock from private land as reported in the literature (Cooke 1998; Devendra & Sevilla 2002) helping to reduce grass and fodder extraction from CFs. According to the communities, they were buying agriculture residues (such as paddy hay, wheat hay and millet hay) and also reducing the number of livestock for the REDD+; there is a trend towards keeping few productive cattle, replacing high numbers of non- productive livestock, in the Hindu Kush region including Nepal (Tulachan & Neupane 1999; Bhattarai & Kindlmann 2012). Although grass and litter make no significant contribution to total carbon stock in the forests, communities have changed their existing practices.

All these changes have costs to communities and their motivation behind these changes could be linked with potential carbon income in the future. Due to these extrinsic motivations of potential REDD+ benefits, the intrinsic motivation of local communities to manage and protect forests could change the fundamental concept of CFs (Deci *et al.* 1999). However, if REDD+ fails to provide benefits as per the expectation of communities, they may not continue their effort to increase carbon stock in CFs and may reverse emissions. There would be a high risk of uncertainty, as mentioned in the literature, regarding the sustainability of forestry sector emissions reductions (Fearnside 2000; Millar *et al.* 2007). While implementing REDD+ activities, creating situations based on the self-determination by communities to choose one out of various options could be better for long term behaviour changes rather than external suggestions and guidance (Deci & Ryan 2000). Therefore, providing better options including freedom for communities to make their own decisions and appropriate benefits might be important in REDD+ CFs.

As Non-Timber Forest Products (NTFPs) constitute lower carbon stocks when compared to trees, the sustainable extraction of NTFPs was continued during the REDD+ project period. Promotion of NTFP businesses based on a sustainable supply of raw materials from forests is an important factor for consideration in REDD+ project design. This could provide income to communities that help to support the livelihood of rural people and reduce poverty at local levels (Edwards 1996). Currently, communities living near *Schima-Castanopsis* and *Pine* forests derive income from NTFPs businesses; this needs to be further explored and adopted in other possible CFs. If NTFP provisions are incorporated in future REDD+ strategies, this may ensure the conservation and sustainable use of these resources. This will also support to conserve biodiversity by linking with the income of local communities as it is found crucial approach to improve degraded forest and reduce poverty (Subedi 2006).

While analysing trade-offs between communities' sacrificed benefits and carbon benefits from REDD+, community foregone costs (monetary value of sacrificed benefits and added contributions of communities) was found to be higher than carbon benefits (monetary value of added carbon dioxide equivalent) in CFs with the REDD+ scheme. Communities received US$ 3.76 in carbon benefits while sacrificing US$ 79.01. This cost does not include the administrative costs including MRV required under REDD+. These administrative costs could be significant and more than small scale forests are able to afford them (Huettner 2012). This will make carbon credit expensive and developed countries that go for compliance market may have less interest in this credit. However voluntary market could have interests on it. In this pilot payment mechanism communities are receiving payment with 16% weightage on carbon increment (Maraseni *et al.* 2014) but if this payment is based on performance, CFUG would receive about 1/6th of the current payment. That would not be of interest of communities therefore carbon additionally based payment mechanism of the REDD+ may not be beneficial in CFs. In a vegetation type wide analysis, a similar trade-off pattern was found. This indicates that REDD+ may not be beneficial for communities from a carbon only point of view. However, communities attach cultural and social values to CF (Maskey *et al.* 2006), which have invaluable benefits for them. Similarly, they want to keep their forests protected for their descendants and to maintain the condition of forests over time. Conserved forests provide environmental benefits including biodiversity (Pandey 2007), watershed management and rainfall patterns (Lu *et al.* 2001) which is important for local people and downstream residents. It would be good to consider these benefits while designing REDD+ project and making decisions about the carbon price.

Although this study found that costs have increased due to wage rates paid to communities for increased numbers of meetings and forestry activities for REDD+, most of these activities are being organized during leisure time for the majority of participants when their opportunity costs are almost zero. For example, most CFUGs organise these activities on Saturdays when job holders are free and opportunity costs are low because there are limited opportunities for cash income in rural areas in Nepal (Kelkar & Nathan 2005); meetings and forest management activities also tend to be organised to avoid the farming season. This is important because more than 70% people living in mountain regions, more than 62 % in hill and more than 58% in terai are engaged in self-employed agriculture (CBS 2011a).

More specifically, while focusing only on added carbon value in CFs, *Rhododendron-Quercus* forests could be a lower priority for carbon focused REDD+ projects developers. But, these forests have important biodiversity co-benefits, providing habitat for pheasants, orchids and leopards (GON 2002) and economic co-benefits from NTFPs (Smith Olsen & Overgaard Larsen 2003). These values need to be respected and proper conservation measures need to be adopted through an appropriate PES mechanism.

The carbon market has been highly volatile (Bushnell *et al.* 2013; Hepburn 2007) and continues to change. Therefore this study assumes three different prices: one is a very optimistic price, one the present price and one a pessimistic price. The cost gap was estimated at US$ 75.25 (i.e. between actual cost US$ 79.01 and benefits US$ 3.76) in the optimistic situation. This gap could be further increased if we used either the present price or pessimistic price. The optimistic premium price can be expected for carbon credits of Nepalese CFs because they can generate various non-carbon benefits such as biodiversity conservation, watershed protection and socio-economic safeguards for poor and indigenous people as agreed in UNFCCC (UNFCCC 2011) but it is still inadequate. Bundling of all the multiple ecosystem service related benefits generated in CFs and appropriate payment for these would compensate for the added costs to local communities under REDD+. PES such as water services is in practice in Costa Rica where it has helped to reward people who are generating these services (Pagiola 2008). Such models of PES need to be explored and adopted for CFs.

Appropriate market mechanisms could help to bring fair benefits at local levels. Most REDD+ talks currently taking place are about the market based mechanism (Kanowski *et al.* 2011; Lederer 2011; Pirard 2008); however, this mechanism may not be beneficial for CFUGs due to the higher costs to communities. This study found that the costs to communities were higher than the present market price (World-Bank 2013) which is a similar result to that found by Maraseni *et al.* (2014). Therefore, opportunities for PES and promotion of sustainable NTFP enterprise activities would provide additional income in communities. These can contribute to poverty reduction at local levels as mentioned in United Nations millennium development goal (United-Nations 2007). However, as stated in the literature, it is important that an appropriate benefit sharing mechanism, proper institutional frameworks and governance practices are developed for the REDD+ mechanism (Phelps *et al.* 2010). The CDM mechanism is considered to be complex in terms of its administrative procedures and to have higher transaction costs resulting in limited expansion of projects (Thomas *et al.* 2004; Chadwick 2006; Thomas *et al.* 2010); the REDD+ mechanism needs to be simple and to involve lower transaction costs.

8.8. Sensitivity analysis of foregone benefits of communities for REDD+ mechanism

As mentioned earlier, two of the highly sensitive attributes which affect the foregone benefits of communities are changes in forest products prices and labour wage rates. In this study, 2012 prices or wage rates were used for these attributes. However, due to the expansion of agricultural land and the scarcity of forest resources, the price of forest products, particularly for timber, may increase faster than the inflation rate (Clark 2001; Apsey & Reed 1994). Similarly, due to exponential growth in migration; labour scarcity is growing year by year. For example, from 2001 to 2011 the number of people who emigrated increased by 25 times from 76,000 to 1.9 million (World Bank, 2011a, 2011b) and the rate is even higher in recent years.

Therefore, the labour wage is highly likely to increase in the future. As noted, the forgone benefit of REDD+ project is already much higher than the additional income from carbon. Increasing forest product price and labour wage rates will make this situation worse. Therefore, there is no sign of any improvement in forgone benefits, while the income from carbon is unlikely to increase to a level which will compensate for this.

8.9. Performance of REDD+ projects in CFs

While evaluating the REDD+ project, evaluation of increased carbon sequestration capacity of forests and benefits to communities is taken as outcomes in this study. As mentioned by Liu and Walker (1998), an evaluation cycle covering three components namely behaviour, performance and outcome, can be applied to the REDD+ project (Fig 8.1). Assessment of these components could provide an idea about the appropriateness of the REDD+ project for CFs.

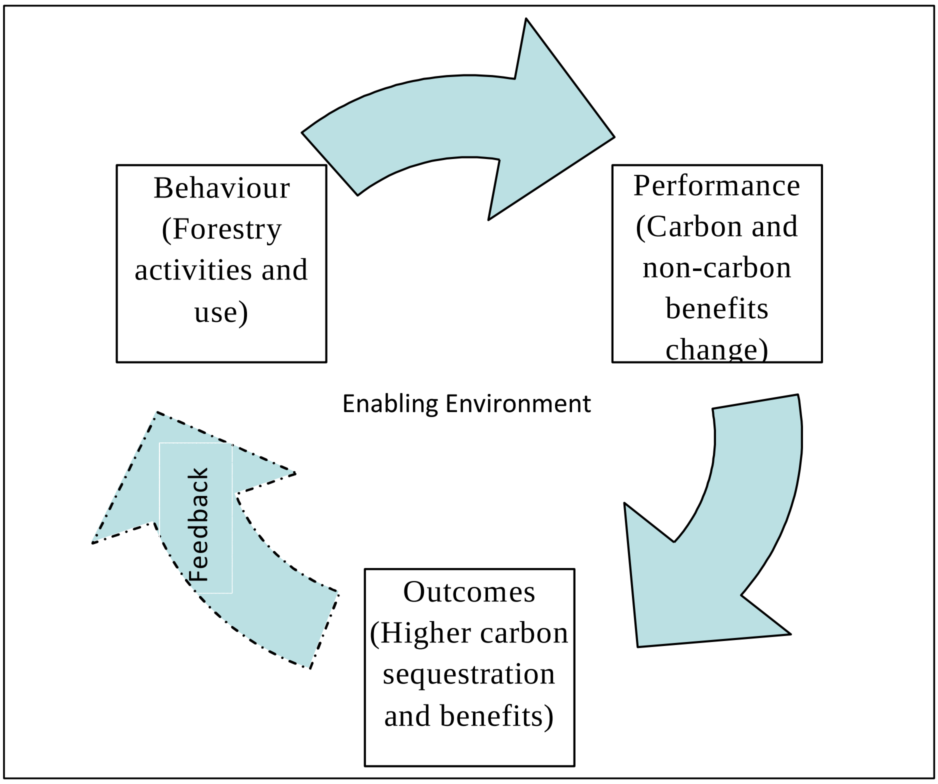


Figure 8.1 REDD+ project performance cycle can be used during REDD+ evaluation *(adopted from Liu and Walker (1998))*

Since REDD+ is a newer mechanism than the existing CF practices, CFUGs has changed existing forest management and use behaviour. This study found changed behaviour particularly in forest improvement activities (silviculture activities, plantation, controlling of ongoing biomass reducing activities), meeting processes to increase participation of users and committee members and deliberation about forest management and benefit sharing decisions, extraction of forest products and use of alternative energy sources (biogas) and low fuel wood using ICS. As stated in the literature, this behaviour had affected biomass carbon in forests (Agrawal *et al.* 2011;

Pandey *et al.* 2013). Although, general rules and guiding principles of CFs are the same in the study area, socio-economic factors can result in contextual differences and induce CFUGs to change those behaviours (Maskey *et al.* 2006; Horn *et al.* 2012). In this study, CFUGs with dominant *Schima-Castanopsis* and *Rhododendron-Quercus* forests in Dolakha aimed to generate income from NTFPs. In those forests, mainly wintergreen (*Gaultheria fragrantissima*) and Lokta (*Daphne* spp) related enterprise activities, in addition to forest management, were being carried out and forest management activities were designed and implemented accordingly (Acharya 2005). Since, the forest management practices of small scale forest owners are affected by their management goal (Hugosson & Ingemarson 2004), setting apropriate goals in REDD+ CF is important. Communities aiming only to promote carbon stock in the forests would promote limited numbers of fast growing trees species and change practices to reduce the extraction of forest products. This may not be beneficial in long term.

The results of changed behaviour of CFUGs under the REDD+ mechanism would be carbon stock increment and co-benefit. If communities had changed their behaviour in a positive ways for REDD+ activities, that may help to increase higher carbon stock. In addition to carbon stock, socio-economic and environmental non-carbon benefits are considered as equally important outcome of REDD+ (UNFCCC 2011). Similarly, support for the generation of possible non-carbon benefits such as biodiversity conservation in CFs (as mentioned in Pandey 2007), protection of forest ecosystems services (Millennium Ecosystem Assessment 2003) regulation of the water cycle (Daily 1997; Nelson *et al.* 2009), continued supply of wild food and non-timber forest products benefits (Edwards 1996; Aryal *et al.* 2009) is important. This study found that CFs were performing well in carbon stock benefit which was higher in middle altitude sub-tropical forests with dominant *Schima-Castanopsis* and *Pine* species but lowest in *Rhododendron-Quercus* forests. However, the sacrifices made by communities were higher than the potential income from the REDD+. For *S. robusta*- mixed broadleaf forests benefits sacrificed were highest while they were was lowest in *Rhododendron-Quercus* forests. Higher potential increment from carbon benefits perspectives for *Pine* and *Schima-Castanopsis* forests may attract REDD+ project developers more.

Since safeguarding non-carbon benefits is a key issue in REDD+ (Visseren-Hamakers *et al.* 2012), REDD+ CFs must be able to maintain non-carbon benefits. However, if the project does not provide incentives to maintain non-carbon benefits, poor people may only focus on carbon benefits because communities want income from their forest conservation efforts (Subedi 2006). However, benefit sharing mechanisms for non-carbon benefits are yet to be developed at the international level (Angelsen *et al.* 2012), though they will potentially come in the future. There are few examples of local or regional mechanisms that may be beneficially adopted. Payment for water resources to upstream users in Costa Rica (Pagiola 2008) is one. This could be adopted in Nepal because CFUGs supply water for drinking, hydropower generation and irrigation which could be included in the payment mechanism. However, currently the Forest Act of Nepal (GoN 1993) does not have clear provision for the PES. In practice, a payment transfer mechanism has been initiated by Kulekhani hydropower in Nepal but no proper institutional framework has been developed. Now, some revenue comes to local bodies through government systems (Joshi 2011) but this may not be channelled to the proper people as it expected in

PES. Therefore an appropriate model needs to be adopted in the study areas where farmers who use irrigation water, Hydropower Company and the municipality who use water from the watershed are encouraged to pay for the sustainable supply of water for the long term operation of those systems. Recreation and biodiversity conservation are also important ecosystem services (Subedi & Singh 2008) that can be linked to a payment mechanism. However, there is no clear payment mechanism developed at the local level apart from some practices to take fees from tourists in national parks and distribute certain moneys to the surrounding communities for local development activities (Nepal 2000; Goodwin 2002).

As ecosystem services are an outcome more of landscape level forests management than individual CFs (Goldman *et al.* 2007), a proper institutional set up would be important covering all watershed level stakeholders. This landscape level institutional set up may be helpful for both conservation and benefit sharing practices; however, there is a possibility of undermining participatory decision making process and recentralising the devolved decision making authority from CFUGs. As discussed in literature, there is also a risk that forest management would be recentralised through the REDD+ mechanism (Phelps *et al.* 2010).

Behaviour of the CFUGs changed and was able to improve forest status after they took on forest management roles at the inception stage of CF (Acharya 2002; Kanel & Kandel 2004) and further changed to increase carbon stock in forests by sacrificing existing benefits for REDD+. This could be the outcome of the raised level of interest of CFUGs in keeping good forests for future generations and securing the supply of forest products for their own benefit through REDD+ carbon benefits. This study found that the potential for REDD+ benefits was one of the motivating factors for these changes; therefore, it is uncertain whether these management practices will be continued in future if the benefits are not experienced by communities.

As mentioned in other literatures regarding successful community forestry projects (Gautam *et al.* 2004; Pokharel 2011), favourable international and national policies and better market mechanism for carbon and non-carbon benefits are important to generate better REDD+ outcomes. If this enabling environment is not supportive for the REDD+ in CFs, it may provide perverse incentive to local communities and may not function well in the long-term.

8.10. Contemporary issues in REDD+ and REDD+ CFs

<u>Governance practice and multi-stakeholder co-ordination in REDD+ CFs</u>: The REDD+ incentive mechanism involves multiple stakeholders who have a stake or interest or right in the forest resources and include those that will be affected either negatively or positively through the mechanism (Gomes *et al.* 2010; UN-REDD 2012). It involves complex multi-level and multi-stakeholder processes (Cadman & Maraseni 2011; Corbera & Schroeder 2011) aimed at fulfilling multiple goals beyond emission reduction. There is a challenge to build common understanding among those stakeholders (Ihor & Keeton 2009). Even in CFs, there were several stakeholders involved before REDD+ including government agencies, forest users, private sector entities, non-government organisations, indigenous people and other

forest dependent communities. While CFUGs are getting involved in the REDD+ mechanism, each of them may have some specific interests in the mechanism therefore coordination and collective action would help deliver better outcomes for the project (Angelsen *et al.* 2012). However, in coordination process some stakeholders may need to compromise their interests for REDD+ (Thompson *et al.* 2011). Therefore participation and deliberation of all stakeholders in decision making and implementation of REDD+ is important to facilitate coordination and address such issues (Cadman & Maraseni 2012). Among these stakeholders, safeguarding the interests of local communities and indigenous peoples are considered a key focus (UNFCCC 2011); therefore, securing free and prior informed consent from local communities is suggested during the designing phase of the project (Lawlor & Huberman 2009). As a CFUG has many subgroups working together (Varughese & Ostrom 2001), the REDD+ governance mechanism is expected to give more emphasis to representation in the decision making process and the benefits received by vulnerable and resource dependent groups within a CFUG and to design a program which ensure their traditional rights and livelihood benefits. This may need to develop a new institutional set up, mechanism and process than existing CFs. Similarly, present land tenure system of CFs may need to further clarify because land tenure is important in REDD+ market mechanism (Karsenty *et al*. 2014).

<u>Appropriate scale of REDD+ project in CF:</u> Discussion about the appropriate right scale for REDD+ projects is going on at the global level. There are three proposals of geographical scale for REDD+ projects; these are the sub-national (including project scale), national and nested scale highlighted in the literatures (Angelsen *et al.* 2008; Clements 2010; Okereke & Dooley 2010; Minang & van Noordwijk 2013). A sub-national or project level mechanism covers a small landscape or project area in developing countries; national level takes all forests of a country as one project; and the nested scale combines both national and sub-national approaches. A country can make decisions about the scale of REDD+ applied to facilitate the mechanisms and most countries have initiated subnational level projects at the beginning (Angelsen *et al.* 2008).

While comparing possible governance practices, leakage possibility, equity and costs of these three scales, sub-national and nested options seem better for CFs (Table 8.4). As the sub national level REDD+ is small and comparatively easier to start at pilot stage, it could attract private sector involvements (Angelsen *et al.* 2008). However, there is a possibility of leakage where communities can shift their forest product extraction activities from the project area to outside forests. This would not be an issue in the case of a National approach (Herold & Skutsch 2011). If the three watersheds of the study decide to go for REDD+ projects, each watershed could be one sub-national project or the aggregated area of all three could be one project. Both leakage and permanence possibilities in sub-national REDD+ projects are always suspected (Pedroni *et al.* 2009). Therefore there is uncertainty about the capacity to maintain carbon stocks in the long term if no proper mechanism is developed to ensure that the forest product demands of communities are fulfilled by, by for example promoting alternative energy (biogas and solar) for fuel-wood reduction and encouraging plantations on unproductive private lands. Similarly, if proper benefit of the REDD+ is not channelled to CFUGs, people may reverse activities that have been modified to take advantage of the REDD+ benefits and carbon may be released back to the atmosphere. Since project level REDD+ could involve fewer stakeholders than national level projects, a focus on poor communities could provide equitable benefit to communities. However it is difficult at the national level at which elites of society may benefit from their access to information that flows from national structures in CFUGs (Kanel 2004). Similarly, a national approach could result in recentralisation of CFUGs' decisions making authority and the possible exclusion of forest dependent communities in project design and implementation and benefits sharing. This likely change in institutional and benefit sharing mechanism of CFs can create social instability. Therefore, there is a need for the careful design and implementation of REDD+ to deal with these aspects if a country wants to go for national approaches. In terms of transaction cost (administrative and MRV costs), sub-national and nested scale REDD+ mechanisms could require higher benefits per CO_2e than the national level due to the experts input and disaggregated data required (Angelsen *et al.* 2008). However, the MRV cost can be reduced by involving local communities rather than experts only (Fry 2011; Larrazábal *et al.* 2012). Therefore, an appropriate protocol about community monitoring at global and local levels to maximise community involvement in the MRV process would be beneficial (Larrazábal *et al.* 2012).

Considering positive and negative aspects of these approaches, a nested approach could be a better option for countries. The nested approach provides opportunities for both sub-national and national REDD+ projects (Angelsen *et al.* 2008). Now, Nepal has agreed on the nested approach of the REDD+ mechanism (GoN/MFSC/REDD-Cell 2011) which is a good decision that allows the design of REDD+ projects covering certain CFUGs at the sub-national level. This will likely not hamper existing decentralised and participatory forest management practices. However, as stated in the literature there are challenges in establishing harmony between national and project level REDD+ project activities (Angelsen *et al.* 2008). As mentioned in the literature (Bushley & Khatri 2011; Corbera & Schroeder 2011), proper multi-stakeholder coordination mechanisms and clear vertical and horizontal linkages between institutions would be important to addressing transparency issues, proper MRV, leakage control, the safeguarding of socio-economic and environmental benefits and marketing activities. This may ensure harmony between different REDD+ projects.

Table 8.4 Scale of REDD+ project for CFs and possible issues

Project scale	Description	Governance	Leakage and permanence	Equity	Cost
National	Country level REDD+ project covering all forests	• government ownership • less participatory • re-centralization of CFs • top down • multi-stakeholder • policy failure	• address domestic leakage • permanence depends in policy and practice of stakeholder	• risk of elite capture • difficult to set up a proper benefit sharing from central to local	• reduce MRV and transaction cost for per CO_2e
Sub-national (Project level)	REDD+ covering a certain areas or project within a country	• direct participation of local communities and IPs in decision making and benefits • weak participation of government body	• domestic leakage possibility • permanence depends in policy and practice of communities	• higher participation of poor • better continuation of CF practices and benefit sharing	• higher MRV and transaction cost for per CO_2e
Nested	A flexible mechanism start with sub-national level REDD+ and gradually move to national level or co- existence of both	• harder in harmonisation between two approach	• control leakage	• encourage participation and proper benefit sharing • poor people can get benefit from REDD+	• higher MRV and transaction cost for per CO2e (need disaggregated data)

Source: Angelsen *et al.* (2008), Herold & Skutsch (2011), Pedroni *et al.* (2009)

Safeguarding non- carbon benefits in CFs: As forests provide goods and services to local poor people in developing countries (Vedeld *et al.* 2007), the REDD+ mechanism would not be expected to make their economic situation worse with the protection of forests. This is clearly mentioned in the UNFCCC agreement (UNFCCC 2011) about developing safeguard strategies in REDD+ projects. The contribution of forests to poverty reduction and environmental sustainability has been highlighted and agreed in many international forums, including article 20 of the CBD, UNFF and UNFCCC COP 16. According to the CBD, international support is needed to address the overriding socio-economic development and poverty reduction priorities of developing countries (CBD 1992). Similarly, enhancing the contribution of forests to achieve poverty reduction and environmental sustainability is an approach agreed in the UNFF (UNFF 2011). Therefore REDD+ mechanisms, as agreed in the UNFCCC COP 16 in Cancun (Ehara *et al.* 2013), need to respect these provisions while designing and implementing project activities. In this study, CFUGs are contributing to increases in carbon stock but are focusing on timber trees. The carbon oriented CFs may reduce the numbers of slow growing trees in forests, resulting also in the reduction in non-carbon benefits (socio-economic, biodiversity, water). In order to secure socio-economic benefits for local communities, it would be beneficial to implement Pareto optimisation approach. Pareto improvement is an important welfare economic concept in which the allocation of goods among individuals is designed to make at least one individual better off without making any other individual worse off (Chou & Talmain 1996). In REDD+ CFs, it has been expected that changing existing practices to increase biomass carbon stock would not make community's existing livelihood situations worse given the provision of alternatives and increased socio-economic security.

Suitable market mechanism for REDD+ in CFs: Two main payment mechanisms have been discussed for possible REDD+ financing; namely, fund based and market based (Okereke & Dooley 2010; Streck 2010). In the fund-based approach, a common fund is created and carbon credit is purchased by the fund which is mostly created by voluntary financial contribution and tax (Skutsch & McCall 2010). These funds have the flexibility to be used in supporting REDD+ activities, and/or delivering performance based payments, and can therefore also receive non carbon benefits (Brown *et al.* 2008). However, there is a possible issue around reduced payment capacity as the voluntary carbon price differs from a market based mechanism (World-Bank 2013). On the other hand, the market based mechanism is a mandatory mechanism of carbon trade (Busch *et al.* 2012) in which a cap and trade mechanism could possibly follow under market based REDD+ mechanism (Pedroni *et al.* 2009). Similar to the CDM, an emission reduction cap (i.e. certified emission reductions (CER) given to a country) has been achieved through buying credits from REDD+ projects of developing countries. Although, market based mechanisms for REDD+ can provide opportunities to sell large amount of carbon credits generated in developing countries, it needs to be highly competitive (Lubowski & Rose 2013). While global policy for market based REDD+ is evolving, FCPF (Westholm 2010), bilateral fund, Amazon fund (Moutinho *et al.* 2011) and green climate fund (Elias *et al.* 2014) have been initiated to fund REDD+ pilot activities in developing countries. However, understanding the operational aspects and outcomes of these funds in the development stages of the program is limited.

This study found community cost tends to be higher than the potential carbon revenue from REDD+ in the competitive market (World-Bank 2013), therefore CFUGs could benefit if they follow fund-based approaches to get better payment for their small holder forestry practices, generating non-carbon benefits and carbon benefits. As stated above, communities are highly dependent on forest resources and they need to change their forest product use behaviours for REDD+ carbon which would only continue in the long term if poor rural communities can get ex-ante incentives that could be possible in a fund-based approach. Similarly there are possibilities to generate over or under debiting the carbon credits in forestry projects (Murray *et al.* 2007) which needs a proper monitoring mechanism and a fair estimation of discounting rates.

8.11. Ideal CF for REDD+ benefits

Since REDD+ includes both reducing existing emission levels and increasing carbon sequestration capacity in forests (Angelsen *et al.* 2012), conserving biomass carbon in old aged trees and promoting growth of young aged trees in forests to attain a higher level of carbon stock are important. The study shows that it is possible to increase carbon stocks in CFs for the REDD+ incentive mechanism if only the carbon stock increment is considered, although all CFs are not equally benefited from REDD+ mechanism. Individual CFs differs in terms of their socio-economic and biophysical characteristics (Gilmour & Fisher 1991) and these characteristics affect the biomass carbon stock differences. Comparatively, CFs with the following characteristics tends to have a better possibility for increasing carbon stock through a REDD+ project:

- <u>CF with large per capita forests available:</u> As noted, if CFUGs have larger per capita forest available, they can increase carbon stocks to a greater extent than smaller ones (Table 6.5). As rural people are highly dependent on forest resources (Adhikari *et al.* 2004), they fulfil their needs from CFs, private forests, agriculture land, nearby national forests and purchase from markets (Thoms 2008). However, some CFUGs may have limited alternative supply source and can only fulfil their needs from their CFs. In this case, a large per capita forest would be better for REDD+ performance. It is obvious that, if communities are extracting the same quantity of forest products from the forests, they can better increase carbon stocks in larger per capita forests than in those of smaller size. The areas of CFs in Nepal range from less than 1 ha to above 4000 ha. Out of 17, 808 CFUGs of the countries, more than 50% are associated with CFs of less than 50 ha in area with less than 0.12 ha per capita allocation while less than 100 CFUGs are above 1000 ha area with above 4.0 ha per capita allocation (CFD/DoF 2013). Therefore the size of forests could play an important role in the outcomes of REDD+ projects in CFs. The productivity of forests also affects yield in forests (Pretzsch 2010); however, where productivity situations are similar, per capita forests affect total carbon stock in forests.

- <u>CFUGs with large agricultural land areas:</u> This study found that CFUGs with larger areas of agriculture land have higher carbon increment rates (Table 6.6). The majority of people in Nepal are farmers (CBS 2011b) and their rural farming practices are interdependent with forest resources (Adhikari *et al.* 2004). Adhikari *et al.* (2004) found that households with larger agriculture land holdings were keeping more livestock and using higher quantities of forest products from CFs than smaller land holdings. This result differs from the findings in this study. This is because local communities have initiated the keeping of productive livestock by reducing the numbers of unproductive livestock in the study CFUGs. This is also supported by a study conducted in the Hindu Kush region including Nepal in which people were replacing high numbers of non-productive livestock (Tulachan & Neupane 1999), which might have reduced the need for forest products. Additionally, people having larger areas of agricultural land can grow more agricultural products and have additional options to fulfil their forest products needs. Similar to other findings in the literature (Gilmour & Nurse 1991), people were planting trees on private uncultivated land, so if CFUGs have more non-cultivated lands, they can grow more forest products. For private plantations, REDD+ project had provided seedlings and technical guidance (ANSAB/ICIMOD/FECOFUN 2013).

- <u>CFUG with high proportions of households using alternative energy:</u> This study found higher carbon stock increment in CFs where a higher proportion of households use alternative energy. Most rural people living in developing countries, especially in Asia and Africa, use wood as the main source of household energy (May-Tobin 2011). This is higher in Nepal where more than 80% of people use fuel-wood for cooking and heating purposes (WHO

2006). In order to reduce emissions from fuel-wood extraction in CFs, the use of alternative energy sources such as biogas, petroleum energy and ICS would be beneficial (Bhattacharya & Abdul Salam 2002; Katuwal & Bohara 2009). However, while alternative energy use can reduce forestry sector emissions, burning of petroleum energy contributes to GHG emissions (Kumar *et al.* 2003). Therefore replacement or reduction of fuel-wood energy use by promoting ICS, solar, biogas or wind energy would be useful for REDD+ benefits rather than promoting LPG, kerosene, diesel, coal (Kumar *et al.* 2003; Zhou *et al.* 2009).

- <u>Reduced extraction of timber and fuel-wood:</u> Reduce extraction of timber and fuel-wood from forests can increase stocking rates, basal areas and height of trees in forests (Chettri *et al.* 2002; Kumar & Shahabuddin 2005). As mentioned by Chettri *et al.* (2002), fuel-wood extraction reduces wood biomass productivity in forests. The growth rate of trees is age and species-specific (*Thomas et al.* 1999) but if trees are dense, this may reduce overall carbon stock than that of sparse forests, probably due to competition for light, moisture, nutrients and minerals. The growth rates of trees are also affected by altitude and other environmental factors (edaphic, topographic, and climatic) (Khanna 2004). Therefore, if CFUGs are extracting fuel-wood from high density stands, extracting bent and unhealthy trees only may help the growth of remaining trees and increase carbon stocks. However communities are carrying out thinning and extraction activities in CFs and there is less chance of having highly dense forest stands. Therefore, the study found increasing biomass carbon in forests where extraction was less than those subject to higher extraction. The fundamental objectives of CFs were to provide a subsistence supply of forest products and to improve forests; existing forest policy allows CFUGs to harvest certain amounts of the increased quantity of forest products (CFD/DoF 2002). However, they may reduce extraction (less that the allowable cut) for REDD+, but reduction may not be possible because rural people are highly dependent on forest products and it is not fair to implement strategies to reduce extraction without providing alternatives for REDD+ carbon benefits. Moreover, if the REDD+ project does not allow local communities to harvest forest products in CFs without making alternative arrangements, communities may shift their forest product extraction to surrounding forests, increasing the possibility of leakage. Therefore, reducing extraction while providing alternative options is important to increase the carbon sequestration capacity of CFs.

- <u>Have more fast growing species</u>: Tree species can be categorised according to growth characteristics into fast, medium and slow growing species (Korning & Balslev 1994). A fast growing species can increase carbon stocks more rapidly than slow growing species; therefore, a CF with dominant fast growing species can result in higher carbon stocks (Smith *et al.* 1997). In this study, *Pine* and *Schima-Castanopsis* are fast growing trees at a younger age than *S. robusta* (Jackson 1994) and CFs with these trees dominant and at higher growth stage on the sigmoidal growth curve (Figure 8.1) will have higher increment rates. If a REDD+ project incentivises additional carbon only, these forests will be more beneficial. However, for non-carbon benefits particularly from a biodiversity conservation point of view, lower altitude forests with dominant *S. robusta* and mixed broadleaf forests in the study area have higher tree species richness. The biodiverse forests provide many essential services to humans that are important for the future sustainability of the environment and society (Pimentel *et al.* 1997). Therefore it is important to develop a mechanism that can maintain multiple species in the REDD+ mechanism.

- Appropriate incentive mechanism for CFUGs: CFUGs can increase and maintain carbon stock in forests if they get REDD+ incentives to compensate for their sacrificed benefits. This study found higher trade-offs between foregone benefits of communities and carbon benefits. Therefore, while comparing with optimistic carbon price and the present increment of carbon stock, communities do not get payments to compensate their sacrificed amount for REDD+, going against welfare economic theory “Pareto improvements” (Hochman & Rodgers 1969; Chou & Talmain 1996). As carbon sequestration has global benefit, REDD+ should pay appropriately without worsening the existing economic situation of local forest user communities. It was also agreed in the 16th session of UNFCCC (2011) to safeguard socio-economic aspects of local communities and indigenous people while implementing REDD+. Similarly, in community based management systems, local people should have some economic motivation to conserve forests in the long run and their conservation activities should provide an income to them (Subedi 2006). REDD+ with proper compensation mechanisms, as well as increased access to alternative options to meet the forest products requirement of local people, is helpful from a welfare perspective to local poor people and also for the effective long term implementation of REDD+.

- Younger age of the forest stands: Tree growth follows a sigmoidal pattern by age (Birch 1999; Clark & Clark 1999). At the beginning of the juvenile stage, the growth rate of trees is slower and they may struggle for establishment. As shown in Figure (8-1), forests with trees of juvenile age had low growth rates forests with medium age have higher carbon stock growth and this was slower again in forests of older aged trees. Young forests may not get carbon benefits based on present carbon growth capacity; however, this is important for long term benefits. After the juvenile stage, established trees show a rapid carbon stock growth pattern. In this stage, CFs can get higher carbon gains with protection and management activities. In this study, most of the CFs fell into this category. However, most of the middle altitude area forests steeper rates of growth than others because they had higher populations and high degradation levels before the CF initiatives. In sigmoidal growth pattern, older aged forests can have less capacity to increase carbon stock. If CFs have higher numbers of old aged trees, they have maximum carbon stock compared to younger forests. This study found middle altitude forests have younger aged trees which have potential to higher growth rates and seem better for REDD+ projects for carbon benefits.

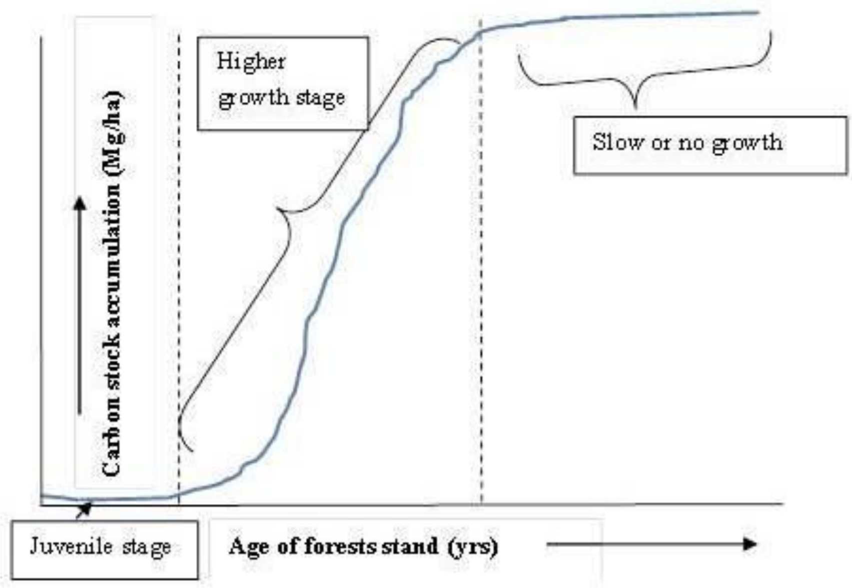


Figure 8.2 Theoretical growth pattern of carbon stock in forests *[Adopted from growth pattern of trees mentioned in literatures (Birch 1999; Clark & Clark 1999) which was found similar in this study]*

Degradation stage of forest of CFs: Neither fully stocked nor highly degraded CFs are likely to be beneficial for REDD+ carbon benefits. Fully stocked old growth forests have limited space to increase stem volume (Smith *et al.* 1997) and carbon stock. Knowledge about the level of degradation of forests when CF and REDD+ CFs are initiated would be helpful in designing REDD+ projects. As most CFs in mid-hill regions were initiated to control the further degradation of forests (Gilmour *et al.* 1989), communities had initiated conservation activities and reversed the forest status. But if forests are highly degraded and have lower soil productivity (Islam & Weil 2000), they may not have the capacity to increase carbon stock. Based on the current condition of CFs, sparse forests tend to be more degraded. CFs that have younger trees, have the potential to grow higher carbon stocks by protecting them and reducing extraction. These CFUGs can get higher benefits from the REDD+ mechanism. There is high possibility that incentives may be given to people who have previously extracted old trees and only started conservation after the REDD+ project commenced.

CHAPTER NINE

SUMMARY, CONCLUSIONS AND RECOMMENDATIONS

9.1. Introduction

The overarching goal of this study is to evaluate the sustainability of the REDD+ project in community forest (CF) systems by considering carbon stock and costs to communities. Within this goal, the study estimated carbon stock and annual carbon stock changes in CFs by dominant vegetation types, estimated technical potential carbon stocks of undisturbed forests and actual carbon stock in CFs by dominant vegetation types, identified and analysed key factors affecting carbon stock changes in CFs, and estimated trade-offs between carbon stocks and net sacrificed community benefits under REDD+ in CF. The study has carried out a comprehensive evaluation of a pilot project performance which was implemented in three watersheds (i.e. Kayerkhola Chitwan, Ludikhola Gorkha and Charnawati Dolakha) covering 105 CFs with five major dominant vegetation types (i.e. *Schorea robusta,* mixed broadleaf, *Schima-Castanopsis*, *Pine* and *Rhododendron-Quercus* forests) in Nepal.

Compared to other REDD+ studies, this study brings knowledge from pilot demonstration projects using repeated carbon pool measurement in CFs. Other studies review and discuss theoretical perspectives and cover mostly government management forests. Those studies have missed the CF system which is an important forestry system, engaging mostly forest dependent local people of developing countries and with potential to engage in the proposed REDD+ mechanism. CF is important from both socio-economic and environmental perspectives. While the policy framework for the REDD+ mechanism is in the preparation stage at international and national levels, learnings from pilot projects would be helpful for the design of appropriate policies to be implemented for REDD+ in CFs. This study provides a comprehensive knowledge base to REDD+ project developers and communities involved in designing REDD+ projects and to policy makers while formulating polices with regards to REDD+ in CFs.

Based on the previous chapters, this chapter provides a summary of the major findings of this study, puts forward research contributions, highlights research implications and makes suggestions for further research.

9.2. Summary of major findings

In order to address the above mentioned goal of the study, the study set four objectives. The first of these was to analyse biomass carbon stock and change in biomass in CFs by dominant vegetation type; the second was to identify gaps between technical potential biomass carbon stock in undisturbed natural forests and carbon stock in CFs; the third objective was to identify key factors affecting biomass carbon in CFs; and the fourth was to estimate the trade-off between community foregone benefits and carbon benefits. The detailed results were presented in chapters 4, 5, 6 and 7 and discussions in chapter 8. Here, the major findings of the study and the implications for the design of REDD+ projects and formulation of REDD+ policy for developing countries are summarised.

9.2.1. Distribution of different sized trees in forests and carbon stock dynamics in CFs by vegetation types

Among different sized trees, recruitment (i.e. sapling) stocking rates were found to be higher in all CFs with a gradual reduction toward larger sizes (i.e. trees). This distribution pattern generates a continuous supply of biomass because if larger trees are removed from the forests, younger will occupy the vacant space. However, the stocking rates of each size of trees differ by vegetation type. Compared to the reference year, 2010, both saplings and trees are increasing with REDD+ project activities in the years since in most of cases. This shows communities are able to change the structure of forests through their forest management activities. However, while regeneration in sparse *Rhododendron-Quercus* forests is fostered, stocking rates of sapling in sparse *Schima-Castanopsis* forests and *Rhododendron-Quercus* forests have declined after the implementation of REDD+ project activities. Therefore the protection of saplings in sparse forests during thinning and harvesting could be helpful in sparse forests of both vegetation types. In the 2010 reference year, carbon stock was higher in *S. robusta* forests followed by mixed broadleaf and lowest in *Schima- Castanopsis* and *Pine* forests whereas in case of carbon stock changes, *Pine* and *Schima-Castanopsis* forest increased to a greater extent than others. Therefore, both incentivisation of *S. robusta* dominant forests as well as *Pine* and *Schima-Castanopsis* forests are important for REDD+ aims. Similarly, carbon stock and change in carbon stock in CFs are found to differ by dominant vegetation types. Even within one vegetation type, dense canopy and dominant trees at higher growth stages (i.e. young age after juvenile stage) in forests can increase carbon stock to a greater extent than sparse forests and older aged stands.

9.2.2. Potential growth of carbon stock in CFs

Comparing the technical potential biomass carbon stock in *S. robusta* forests, CFs were found to perform less well in maintaining present carbon stocks. Lower aged forest stands showed less difference while there was a higher difference in older aged stands. This shows that communities were extracting or losing older trees at a greater rate than younger ones in CFs. Among dense and sparse canopy forests, dense forests had fewer gaps available than sparse forests with technical potential carbon stock. Therefore, there may be higher potential to increase carbon stocks in CFs up to the technical maximum level in sparse forests than in dense. Similarly, dense forests have comparatively higher stocking rates of trees and so higher carbon stocks in forests. Therefore the optimum stocking rates of trees in forest stands can be predicted and proper silviculture operations organised for both sparse and dense forest types. Community forest user groups (CFUGs) may be able to increase the biomass of carbon stock and reduce gaps to the theoretical maximum level of undisturbed forests by fully protecting forests and stopping biomass reduction factors.

Limited works were found to estimate theoretical maximum carbon stock in undisturbed forests for any of dominant mixed broadleaf forests, *Schima-Castanopsis*, *Pine*, *Rhododendron-Quercus* vegetation dominated forests. Therefore, this study compared two extreme percentile carbon stocks (90th and 10th percentile) in both dense and sparse categories. Both 10th and 90th percentile carbon stock values were higher in dense canopy forests than sparse one. Large gaps between the carbon stocks in plots within each canopy category forests were found as well. In order to reduce such carbon stock differences within one stratum or between two strata in CFs by vegetation type, several important socio-economic and biophysical factors should considered and addressed. These factors are associated with community forest management practices and forest product use behaviour. These key factors are summarised in the following sections.

9.2.3. Key factors affecting carbon stock in CFs

Biophysical factors, mainly the elevation of forests (m asl), average age of dominant trees of forests stand and socio-economic factors including per capita forests, household level agriculture land holding, proportion of biogas using households, proportion of petroleum energy using households and the quantity of biomass (timber and firewood) extraction were responsible for carbon stock differences.

Though these factors affect carbon stocks in all CFs, the level of effect is contextual. For example, factors affecting lower altitude *S. robusta* forests are not the same in higher altitude *Rhododendron-Quercus* forests. CFUGs have successfully changed existing forest resource extraction behaviours and reduced damages in response to the REDD+ project. To achieve these changes, project interventions particularly in distributing improved cooking stoves (ICS) to reduce fuel wood consumption, plantation support, awareness activities and distributed incentives for carbon enhancement focusing on the poor and ethnic communities have a role.

9.2.4. Model CFs for REDD+ projects

CFs with the following characteristics could be ideal for REDD+ benefits:

- CF with large per capita forests
- CFUGs with large per household agriculture land area available
- CFUGs with a high proportion of households using alternative energy
- Reduced extraction of timber and fuel-wood
- CFs with higher growth stages by age
- Have more fast growing species such as *Pine* and *Schima-Castanopsis*
- Having appropriate incentives and payments from REDD+

9.2.5. Trade-offs between foregone community benefits and carbon benefits in REDD+ CFs

Local communities are using forest resources (timber, fuel wood, leaf litter, fodder and grass and grazing livestock) from CFs. In order to increase carbon stock in forests for the REDD+ mechanism, communities have changed existing practices but have incurred additional costs. Generally, these costs were of two types (i.e. costs due to additional efforts made for REDD+ activities), including foregone costs for changed forest management activities and foregone costs due to reduced forest product benefits.

For the REDD+ project, communities had reduced the use of forest products through reduced extraction of forest products (i.e. timber, fuel wood, grass, and litter) and reduced livestock grazing (i.e. cow and goat) which has added costs. In species-wise comparisons in CFs, *Pine* forests had sacrificed the highest level of timber benefits followed by *S. robusta*-mixed broadleaf forests. However, total sacrificed benefits were highest in *S. robusta*-mixed broadleaf forests followed by *Pine* forests and lowest in *Rhododendron-Quercus* forests. There was no reduction, and even some increase, in NTFP income under the REDD+ project. As NTFPs share very little biomass carbon compared to other pools comprising the total biomass carbon of forests, the REDD+ project may encourage communities to increase their NTFPs income through conservation oriented extraction.

There are higher possible trade-offs between community foregone costs (the monetary value of sacrificed benefits and added contributions of communities) and carbon benefits (the monetary value of added carbon dioxide equivalent) in CFs for the REDD+ projects. On average, CFUGs get US$3.76 benefits from biomass carbon by sacrificing US$79.01 per hectare of forest which is much higher than expected. By forest type, CFUGs need to spend US$38.99 in *S. robusta*- mixed broad leaf forests, US$16.30 in *Pine* forests, US$10.02 in *Schima-Castanopsis* forests and US$3.62 in *Rhododendron-Quercus* forests to generate each dollar of benefit from the REDD+ project. This trade-off is less in *Rhododendron-Quercus* forests; however, these forests have lower carbon increment rates. Similarly, *S. robusta* mixed broadleaf forests have higher trade-offs, but these forests also have higher carbon stocks and also more valuable timber trees. Although all forests contributed increased carbon stocks under the REDD+ project activities, not all of these forests deliver benefits when trade-offs are considered. Therefore CFUGs may not gain benefits from the mechanism if it only considers carbon stocks as a commodity. CFs also generates social and environmental benefits. These non-carbon benefits should also be taken into account while making decisions about carbon prices, but these are currently not included in the market mechanism. The most suitable mechanism to follow for REDD+ in CFs is possibly a fund-based and voluntary market mechanism. Additionally, higher trade-offs were also associated with community wages for increased participation in forestry activities including meetings for REDD+; most of activities can be organized during the leisure time of the majority of participants when their opportunity costs are almost zero to reduce costs.

9.3. Contentions made before the study

This research was based on several contentions during data collection, analysis and interpretation. Most of these contentions were supported in this study.

- *Forest biomass (and therefore carbon stocks and sequestration rates) in CF is affected by management practices. These include harvesting and other disturbance practices. Due to these disturbances, actual potential carbon stock in CFs is much lower than technical potential carbon stock in undisturbed natural forests.*

Biomass carbon stock and changes in CFs were also affected by forest disturbances factors such as forest fire, biomass extraction and grazing. With the REDD+ project activities, communities reduced these disturbances thereby increasing the carbon stocks in forests. Compared with the technical potential carbon stock in undisturbed forests, biomass carbon in CFs was less indicating significant potential to increase biomass carbon in forests through the REDD+ project. There is higher potential to increase biomass carbon in sparse forests than dense. Forest management practices which most reduce the harvesting of forest products and control disturbances can deliver higher carbon benefits.

- *Carbon stocks and sequestration rates are possibly affected by various biophysical and socio-economic factors which include altitude, age, forest canopy cover, species type, size of forests, caste heterogeneity, agriculture land holding size, disturbance levels, forest product extraction and use of alternative energy.*

  Of the various biophysical and socio-economic factors, altitude, age, forest canopy cover, species type, size of forests, agriculture land holding size, disturbance levels, forest product extraction and use of alternative energy affect biomass carbon stock and change in CFs. The study found that forests located at lower altitudes, forests with dominant old age trees, dense canopy forests, higher wood density species, larger per capita forests, larger per capita agriculture land holding forests, less disturbances (i.e. fire, harvesting of forest products, grazing) and/or higher proportions of household using alternative energy are likely to have higher carbon stocks. However, these factors are contextual; therefore, assessment of these factors will help in the design and implementation of REDD+ project activities in CFs. There were many caste groups working together in CFs but the study found that caste heterogeneity does not affect carbon stocks if CFUGs have shared goals and perform collective actions.

- *REDD+ incentives may be insufficient, especially in the long term, to offset the economic losses from changing management practices of communities.*

  CFUG's costs for REDD+ were higher than potential carbon revenue. Communities need to spend more to generate additional carbon in their forests, although this differed across dominant vegetation types. Forests with valuable timber trees and high labour wages need to spend more to increase carbon stocks than others. Since rural communities who are managing forests are poor, they expect additional benefits or at least reimbursement of their costs for REDD+ activities in CFs. Therefore, if REDD+ only takes carbon benefits into account and goes for a market based mechanism, this is unlikely to compensate a community's costs. As a result, the outcomes may not be long term and communities may revert to previous behaviours for their livelihood support and emit CO_2 again in similar quantities.

9.4. Research contributions

This research contributes new knowledge in the following areas.

- Research approach/framework: This study assessed the REDD+ demonstration project in CFs using annual measurements of carbon stock changes, changed behaviour of local communities and possible outcomes in terms of carbon benefits and associated sacrificed benefits. This assessment process, by covering all aspects, can be useful in REDD+ project evaluation in CFs in developing countries.

- Design and implementation of REDD+ project in CFs: Carbon stock and change in carbon stock in CFs vary with vegetation type and canopy cover. Therefore, while designing the REDD+ project and benefit sharing mechanism, consideration should be given to forest vegetation and canopy type. This study brings new knowledge that even with community management, REDD+ performance differs and vegetation-specific project activities need to be designed and implemented.

- Key factors to be considered in designing REDD+ project in CFs: This study found that carbon stock and change in carbon stock in CFs differ with variation in socio-economic and biophysical factors. The impact of these factors differs with CF vegetation type. Therefore, species type, canopy cover, elevation, age, size of forests, agriculture land holding size, disturbance levels, forest product extraction and use of alternative energy are key factors that need to be considered in each vegetation types while designing REDD+ project activities.

- Potential carbon increment in CFs with REDD+ project interventions: Although all CFUGs contribute to increased carbon sequestration capacity in their forests, existing carbon stock in the CFs are currently less than the technical potential capacity of forests. Therefore, there is significant space available for the REDD+ project to increase carbon stock in CFs. Comparatively sparse canopy forests have the highest gap and greater potential for increase than dense forests. In age-wise comparisons, old aged forest stands in CFs have higher gaps than younger aged undisturbed forests. This means there are fewer old aged trees in CFs therefore CFUGs need to reduce the harvesting of old trees and create an environment which facilitates an increase in the proportion of old trees in forests to reduce that gap.

- Trade-offs between sacrificed community benefits and carbon benefits in REDD+CFs: This study estimated that CFUGs are able to increase biomass carbon in CFs by changing their existing forest management and resource use practices. These new practices have added costs for communities either through the loss of benefits or by demanding additional efforts for REDD+ activities in CFs. Analysing real time costs or sacrificed benefits to communities and potential carbon benefits indicates that the REDD+ project may not be beneficial in CFs. However, it could be beneficial if: a community's contribution (mostly participation and wages cost) could be arranged during times of minimum opportunity cost (i.e. zero cost or free time of participants); other co-benefits could be bundled together with carbon benefits to get a premium price from REDD+ project in CFs; and possibilities could be explored for a PES mechanism at the local level for water and recreation services.

- Benchmarking for further research: The study of carbon stock increment in CFs involves ecological aspects of forests and behavioural aspects of local communities. There is a need for long term studies to confirm growth trends and the impact of community practices. This study covers four years of data which may not be enough to confirm growth patterns and changes in community behaviour for REDD+ carbon benefits. However, this study will be a benchmark for future long-term studies against which to compare changes in future.

9.5. Research implications

REDD+ is the likely incentive based mechanism developed to reduce forestry sector GHG emissions in developing countries. After the 13th session of UNFCCC (2007), REDD+ is on the agenda as a possible option in global climate change discussions. There is good indication for inclusion of REDD+ provisions in post Kyoto negotiations although no clear policy frameworks have been developed. Therefore several pilot initiatives have been implemented for REDD+ which are expected to generate knowledge and fill the policy vacuum. Some research implications are made based on this study's findings for better designing REDD+ for CFs in developing countries.

9.5.1. Implications for policy making level

Develop a benefits distribution mechanism accordiing to performance of CFUGs: As performance-based payment is the basis of REDD (ie, payment according to quantity of carbon added by the project), this study revealed that present CFs have high potential to add biomass carbon stock. Therefore, REDD+ mechanisms could help to incentivise local forest user communities for additional biomass carbon generated in their forests. Now, all CFs are placed in a single basket and treated in the same way with regard to forest management and subsistence use practices in a country. While considering ecosystem services (including REDD+ biomass carbon), different CFs can contribute differently with their different capacity to generate outcomes. Therefore, incentives are needed which accord to their performance through a fair benefit sharing mechanism. If a CF is generating higher carbon stock, they need to get more benefits than lower carbon forests. Policy should be developed by considering these aspects in order to make the REDD+ implementable in the long term.

Consider degradation status of forests before CF and species domination while designing REDD+ mechanism: Carbon stock is comparatively less in middle altitude forests in Nepal i.e. *Schima-Castanopsis* and *Pine* forests while the potential increase rate is higher in these forests. Similarly, sparse forests have higher potential increase rates of biomass carbon than dense forests. Therefore, REDD+ project should focus on *Schima-Castanopsis* and *Pine* forests and sparse canopy forests for optimal benefit. While REDD+ includes both addition and conservation of existing carbon stock in forests, lower altitude *S. Robusta*- mixed broadleaf and higher altitude *Rhododendron-Quercus* forests should also be considered during REDD+ policy formation.

National and international policies should emphasise the need to bring additional benefits at CFUG level by providing options for payments: CFUGs have changed their existing forest product use practices and forest management activities for REDD+. Due to these changed behaviours and efforts, they have lost benefits and/or increased costs. In comparison to the potential benefits from increased carbon stock, sacrificed foregone community benefits (i.e. costs) are higher. This shows REDD+ is not beneficial for CFUGs. However, if REDD+ benefits were to be expanded from carbon benefits by incorporating socio-economic and environmental benefits, the price of carbon could increase and provide additional income. International and national policy frameworks should be developed in favour of this provision.

9.5.2. Implications for project implementation level

Knowledge to REDD+ project developers: This result represents CFs in developing countries where communities are allowed to conserve and harvest forest products for their subsistence use. It indicates that there is potential to increase carbon stock in CFs in Nepal and community managed forests in other similar developing countries. Therefore, appropriate REDD+ activities and incentive mechanism may be able to increase carbon stock in majority CFs. These results can encourage REDD+ project developers to design and implement REDD+ activities in non-REDD+ CFs with similar forest types.

Possible activities for carbon stock increment in REDD+ CFs: The outcome of the REDD+ project in CFs depends on various factors. Among socio-economic factors, higher proportion of alternative energy using household in CFs and reduction in biomass extraction from forests are key interventions that could help to increase biomass carbon in CFs. These include alternative energy, mainly biogas, in lower and middle altitudes (mostly in warmer sites) with special focus on poor households and the promotion of improved cooking stoves (ICS) in all areas to reduce wood consumption during household cooking and heating. Poor people cannot afford the cost required to install and operate biogas plants therefore upfront financial support could be helpful to facilitate the adoption and use of that technology. ICS is a relatively cost effective intervention to reduce fuel wood consumption. REDD+ project activities should include technical and financial support to promote biogas and ICS wherever feasible in order to reduce fuel wood extraction from forests. In the case of other biomass, efforts to reduce illegal harvesting of trees and facilitate plantation activities (tree, fodder and grass) on unproductive agricultural lands will help to provide additional forest product supply options to communities. Therefore plantation activities and creating environments to grow trees in sparse canopy forests could enhance biomass carbon in REDD+ project.

Considerations to minimise risk of perverse incentives to local communities in REDD+ CFs: Communities have sacrificed different foregone benefits for REDD+ projects in each CF while increasing, by different amounts, the biomass carbon in forests. Therefore REDD+ projects need to develop a benefit distribution mechanism considering these aspects. If this consideration was not made, it would lead to a perverse incentive mechanism which may compromise the effectiveness of REDD+ in the long term. Accessing voluntary markets and seeking possible payments for non-carbon benefits would be helpful.

9.6. Limitations of the study

This study collected and analysed periodically collected carbon pool data in relation to the biophysical characteristics of CFs, community forest product use and management activities. While this study utilises scientific approaches to data collection and analysis, the following limitations should be taken into consideration:

i. This study uses four years' data collected from the field after the REDD+ project activities in CFs in Nepal commenced. Finding on carbon stocks may differ with more data. However, the study gives an indication of carbon stocks in CFs under REDD+ project activities and also provides a basis for further studies.

ii. This study collected real-time data on sacrificed benefits and additional contributions of communities for REDD+. The analysis of the trade-offs between communities' sacrificed benefits and REDD+ carbon benefits does not include indirect costs or benefits to local communities.

iii. Climate change itself can have some effects on biomass growth and biodiversity; however, this has not been considered in this short term study, given lack of data on impacts.

iv. Ages of the dominant tree species in plots are estimated based on observation by experienced local people and forestry technicians. This method is applied in other similar studies but it can give slightly higher or lower results than the exact age.

v. Getting primary data was not possible therefore allometric equations used for the estimation of above ground biomass and so root: shoot ratio and wood density were based on information from the literature.

vi. This study used a yield table developed for undisturbed natural *Shorea robusta* forests to predict technical potential carbon stock. However, undisturbed forest models were not available to predict the technical potential carbon stock for mixed broadleaf, *Schima-Castanopsis*, *Pine* and *Rhododendron-Quercus* dominated CFs. Therefore this study estimated only the gap between higher and lower carbon stocks in plots based on the percentile value of carbon stock in all vegetation types except *Shorea robusta* dominated forests.

9.7. Suggestions for further research

Long term research about carbon stock changes including soil carbon pool: Even though this study attempted to evaluate the REDD+ pilot project activities by analysing four years of inventory data and found CFUGs are contributing in generating additional carbon stock in forests, there is still scope to investigate the results in the longer term to confirm the change trends. Communities have changed their existing forest management activities and forest resource use practices and increased carbon stock in CFs for REDD+ carbon benefits. However, there are uncertainties as to whether these changed practices will persist in the long term or just for few years and whether added biomass carbon will be retained for the long term or release back to the atmosphere after a few years. Using the results of this study as a baseline, further studies generating time series data are recommended to identify trends for biomass carbon growth in CFs. That long term study needs to include soil carbon as well because soil carbon can change in long term REDD+ projects with improving forest productivity and changes in forest use practices of communities.

Detailed economic analysis to assess REDD+ CFs to design economic models with various scenarios: This study included real-time added costs to communities for forest carbon enhancement. The direct cost due to changed forest management and the forest product use practices of communities are included in the accounting however, there could be other indirect costs involved. On the other hand, carbon benefits were estimated by considering the possibility of getting a premium price for a least developed country with respect to non-carbon benefits. Although analysis shows costs are higher than benefits, there is potential to emphasise some activities over others in order to reduce the cost to communities. A further research, particularly detailed economic analysis of various scenarios, are required to assess REDD+ options with various costs scenarios for CFs.

Long term study about trade-off between community cost and carbon benefits: The community costs estimated in this study were unexpectedly higher, possibly due to the early stage of the project. As communities' behaviour can change over time, it is likely that cost at later stages in the REDD implementation may also differ. Therefore, a long term study is needed to understand the trade-off between community cost and carbon benefits.

Share of potential costs and benefits of the REDD+ activities at different community members within a CFUG: This study does not include disaggregated analysis of potential cost and benefits proportions of REDD+ mechanism for individual groups (such as poor, women, marginalised groups) within a CFUG. This might be the same as indicated in other studies about CFs in Nepal which show that an inequitable proportion of the costs are borne by poor and marginalised members of the community (Neupane 2003; Richards *et al.* 2003; Adhikari *et al.* 2004; Dev *et al.* 2004; McDermott & Schreckenberg 2009; Sunam 2011). It is important to analyse both the costs associated with added or changed practices for the REDD+ and benefits received from payments. Therefore a detained study is needed to clarify whether poor and marginalised members are equally benefitted by the mechanism or not.

Technical potential carbon stock in undisturbed forests by vegetation type using time series data: Technical potential biomass carbon in undisturbed natural *S. robusta* forests was taken from the specific yield table for Nepal. But, similar information was not available for mixed broadleaf forests, *Schima-Castanopsis* forests, *Pine* forests or *Rhododendron-Quercus* forests. There is scope to contribute in these areas to enable the assessment of technical potential carbon stock gain in such forests with changed behaviour of communities in CFs. On the other hand, biomass carbon growth in CFs was estimated by using chronosequence data which could vary due to site productivity differences. Studies using time series data would give more accurate growth rates for undisturbed forests and CFs and could be an area for future research.

Remote sensing and GIS based research in future to assess changes: Similarly, carbon stock increases differ across the ranges of biophysical and socio-economic factors in CFs. Though the results of this study indicated key factors responsible for carbon stock, ecological study needs long term data and it is suggested that further studies to quantify the effects of particular factors on carbon stock changes be conducted. However, future studies can use this study's results as baseline data. Further research using spatial and temporal data including GIS and remote sensing data of all climatic, topographic and edaphic factors will be helpful in future.

Impact of climate change on forest carbon stock changes: Climate change is another important factor responsible for changing vegetation dynamics in forests. Although not included in this study, changing climate may affect the rates of carbon stock changes in forests. This study estimated changes over three years from the commencement of REDD+ activities in 2010 and assumed that any possible impacts of climate change on vegetation growth over this period were negligible. However, it can have significant impact in the long term and this factor needs to be added for long term carbon stock growth projections with REDD+ activities in forests. Further research is needed in this area.

Effects of REDD+ projects in biodiversity: CFUGs might be focusing on carbon enhancement for REDD+ incentives. Therefore, there is a possibility of reducing species richness in REDD+ CFs if communities do not get incentives to maintain species richness together with carbon benefits. Biodiversity and species turnover related studies need long term data. Therefore, further studies regarding the effect of REDD+ projects on biodiversity with reference to long time spans is suggested.

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APPENDICES

Appendix A: Checklist for key informant survey

This checklist used for key informant consultation to identify factors affecting carbon stock and change in carbon stock

1. Encroachment and expansion of agriculture land
2. Shifting cultivation
3. Frequency of biomass reducing factors (forest fire, timber harvesting, firewood collection, fodder collection, grass collection, grazing)
4. Weather condition
5. Climate change
6. Resettlement program
7. Infrastructure development
8. Elevation of forests from mean sea level
9. Proximity of forests from motor-able road and from settlement
10. Average age of dominant trees in forest stands
11. Per capita forest areas
12. Caste heterogeneity
13. Household level landholding
14. Average change in livestock
15. Biogas use
16. Petroleum energy use
17. Biomass extraction
18. Grazing
19. Quantity of grass and fodder collection
20. Fodder and grass collection
21. Litter collection
22. Others

Appendix B: Checklist used to collect forest related information from documents available with CFUGs

Descriptions
1. Hand over date (date when CF was legally initiated)
2. Population (Total in CFUG)
3. Forest condition before CF and REDD+
4. Household numbers (total and caste-wise)
5. Average age of forests (average age of dominant trees in CF)
6. Meeting and general assembly (Frequency in year and participation numbers)
7. Income sources
8. Sources of forest products supply
9. Harvesting practices
10. Average agricultural land holding size per household in CFUG
11. Alternative energy (type of energy and adopting households number) use in CFUG
12. Average live-stock numbers per HH (buffalo, cow, goat)

Appendix C: Checklist used to collect costs and benefits data from documents available with CFUGs

Benefits (Quantity extraction)	6/7	7/8	8/9	9/10	10/11	11/12	Price/unit (2012)
a. Timber (species-wise quantity)							
b. Grasses							
c. Fodder							
d. Litter							
e. Fuel wood (species-wise quantity)							
f. NTFPs (total income)							
g. Grazing (cow, buffalo, goat)							
Costs (labour unit and other cost in monetary value)							
A. General assembly							
B. Executive committee meeting							
C. Plantation							
D. Forest fire control							
E. Silviculture operation							
F. Guarding							
G. Harvesting							

Appendix D: Checklist of the questions asked in group discussion

Key questions

1. How was forest status before CF?
2. Why do you want to protect forests? (reasons)
3. Do your group generate incomes from forest? What do you do with forest incomes?
4. What benefits are you getting from forests?
5. What are the major sources of income of community members?
6. What was labour rate in 2012? (per man-day)
7. How do you make forest management related decisions?
8. Which are the timber tree species and preferred timber tree species available in your forests?
9. How communities are fulfilling their forest product needs? (supply sources of forest resources)
10. What do you know about the REDD+?
11. What changes have been made after the REDD+ project activities? Particularly forest product use practices (timber, fire wood, fodder, grass, fodder and NTFPs), decision making processes (meeting frequency and participation), forest improvement activities (guarding, plantation and silviculture operation) and forest degradation activities (fire, grazing, illegal harvesting)
12. How much grass is required for each livestock (i.e. for one cow, one buffalo, one goat) during grazing day and non-grazing day?
13. What have you done to increase carbon stocks in CFs?
14. What is the perspective benefits of the REDD+?
15. What is important to make the REDD+ incentive mechanism more beneficial at community level for long term benefit?
16. What is the observed age of the forests? (based on dominant trees)
17. In your opinion, which forests (i.e. nearby motor able road or far from the road; nearby settlement or far from the settlement) is better (in term of stock and bigger trees in unit area).

Appendix E: A format used to collect forest resource inventory data in each sample plot

(Source: Subedi et al. 2010)

1. Background information

Name of CFUG:	Date:	References of plot
Name of forest (based on species):	Forest type: Natural/Plantation	
Forest area: Natural forest_____ha. Plantation forest_______ha.	Strata type:	
Name of forest block:		
Plot no:	GPS coordinates:	
Name of data recorder:		

2. Plot information

Altitude (m):		
Forest type (Major spp):	Forest disturbance incidence	
	Forest fire symbol: yes/no	Fodder collection: yes/no
	Grazing: yes/no	Firewood collection: yes/no
	Timber collection: yes/no	Forest encroachment: yes/no
Dense/Open	Other information:	

3. Trees (> 5 cm DBH) measurement in 8.92 m circular plot

S.No.	Spp	Diameter (cm)	Angle from eye Height (^{0})		Distance between standing point to tree (m)	Slope angle(^{0})	Tree outward appearance
			Top angle	Bottom angle			
1							
2							
3							
4							
5							
6							
7							
8							
9							
10							
11							
12							
13							
14							

4. Saplings (1-5 cm DBH) measurement in 5.64 m cicular plot

S.No.	Species	Diameter in cm at breast height	Height (m)
1			
2			
3			
4			
5			
6			
7			
8			
9			
10			
11			
12			
13			
14			

5. Regenerations counted in 1m cicular plots

S.No	Species	Total no.	S.No	Species	Total no.
1			8		
2			9		
3			10		
4			11		
5			12		
6			13		
7			14		

6. Information to be collected within 0.56 m radius subplot

Herbs and grasses to be weighed within 0.56 m radis sub plot (all non woody plants < 1 cm diameter)	
Sample packet ID (100 sample to lab at first year):	Total weight of herbs and grasses in plot (Kg):
Leaf litters to be weighed within 0.56 m radius sub plot	
Sample packet ID (100 sample to lab at first year):	Total weight of leaf litters in plot (Kg):

Appendix F: Comparison of biomass (both above ground and below ground) using four year measurement data by vegetation types and canopy strata of CFs in the study areas

Canopy cover	Sapling Biomass (Mg /ha)								Tree Biomass (Mg /ha)								Litter Biomass (Mg /ha)				Other Biomass (Mg /ha)				Total Biomass (Mg / ha)			
	2010		2011		2012		2013		2010		2011		2012		2013		2010	2011	2012	2013	2010	2011	2012	2013	2010	2011	2012	2013
	*AGSB	**BGSB	AGSB	BGSB	AGSB	BGSB	AGSB	BGSB	#AGTB	##BGTB	AGTB	BGTB	AGTB	BGTB	AGTB	BGTB												
Dense *Shorea* forests	4.6 (4.5)	1.2 (1.2)	5.7 (4.6)	1.5 (1.2)	5.2 (4.7)	1.4 (1.3)	4.4 (3.2)	1.2 (0.9)	209.7(140.6)	56.7 (38.1)	224.6(139.2)	60.7(37.7)	231.1(135.5)	62.5 (36.7)	237.6(133.4)	64.2 (36.2)	4.0 (3.9)	4.9 (2.7)	4.7 (2.5)	4.6 (3.4)	0.2 (0.3)	0.2 (0.3)	0.3 (0.3)	0.4 (0.5)	276.4 (177.8)	297.6 (176.2)	305.1 (172.0)	312.3 (169.3)
Sparse *Shorea* forests	4.8 (4.6)	1.3 (1.2)	6.9 (5.3)	1.9 (1.4)	5.1 (3.6)	1.4 (1.0)	5.5 (4.9)	1.5 (1.3)	142.6(100.1)	38.5 (27.0)	146.6 (103.5)	39.6 (28.0)	150.1(98.2)	40.5 (26.5)	153.9(93.4)	41.6 (25.2)	2.2 (2.6)	5.3 (2.6)	5.0 (2.7)	5.1 (3.8)	0.3 (0.3)	0.3 (0.3)	0.4 (0.3)	0.5 (0.5)	189.7 (127.3)	200.6 (130.7)	202.4 (124.6)	208.1 (119.6)
Total *Shorea*	4.7 (4.5)	1.3 (1.20	6.0 (4.8)	1.6 (1.3)	5.2 (4.5)	1.4 (1.2)	4.6 (3.6)	1.3 (1.0)	195.3(135.6)	52.8 (36.7)	207.9 (136.0)	56.2 (36.8)	213.7 (132.5)	57.8 (35.9)	219.7 (130.3)	59.4 (35.3)	3.6 (3.7)	5.0 (2.7)	4.8 (2.5)	4.7 (3.5)	0.2 (0.3)	0.2 (0.3)	0.3 (0.3)	0.4(0.5)	257.8 (171.7)	276.9 (171.9)	283.1 (168.1)	290.0 (165.4)
Dense Mixed broad leaf forests	5.8 (4.0)	1.6 (1.1)	6.3 (3.5)	1.7 (0.9)	4.7 (3.4)	1.3 (0.9)	5.9 (3.1)	1.6 (0.8)	189.1 (140.3)	51.6 (38.6)	203.1 (141.5)	55.4 (39.1)	209.4 (138.7)	57.1 (38.2)	218.5 (141.5)	59.6 (38.9)	2.6 (3.6)	4.3 (2.4)	3.7 (2.4)	5.1 (4.0)	0.4 (0.4)	0.3 (0.2)	0.4 (0.3)	0.7 (0.5)	251.1 (179.7)	271.0 (180.8)	276.6 (177.2)	291.3 (179.5)

Sparse Mixed broad leaf forests	6.4 (4.6)	1.7 (1.2)	4.2 (3.6)	1.1 (1.0)	3.2 (1.7)	0.9 (0.5)	5.3 (3.0)	1.4 (0.8)	108.7 (88.1)	29.4 923.8)	108.4 (86.2)	29.3 (23.3)	109.7 (77.0)	29.6 (20.8)	121.9 (80.5)	32.9 (21.7)	1.1 (2.1)	3.6 (2.6)	3.6 (1.2)	6.0 (2.6)	0.5 (0.4)	0.3 (0.3)	0.3 (0.3)	0.7 (0.7)	147.8 (113.3)	146.8 (109.3)	147.3 (97.3)	168.3 (103.9)
Total Mixed broad leaf forests	5.9 (4.1)	1.6 (1.1)	5.9 (3.5)	1.6 (1.0)	4.5 (3.2)	1.2 (0.9)	5.8 (3.1)	1.6 (0.8)	176.3(136.1)	48.1 (37.7)	188.0 (138.1)	51.3 (38.1)	193.5 (135.4)	52.8 (37.3)	203.2 (137.9)	55.4 (37.9)	2.4 (3.4)	4.2 (2.4)	3.7 (2.3)	5.2 (3.8)	0.4 (0.4)	0.3 (0.3)	0.4 (0.3)	0.7 (0.5)	234.7 (174.3)	251.3 (176.7)	256.1 (173.2)	271.8 (175.1)
Dense *Schima-Castanops*is forests	4.8 (3.8)	1.3 (1.1)	6.7 (5.2)	1.8 (1.4)	6.5 (5.4)	1.8 (1.5)	6.3 (5.5)	1.8 (1.5)	150.9 (101.6)	41.7 (28.4)	165.5 (103.1)	45.7 (28.8)	172.8 (104.0)	47.7 (28.8)	183.6(103.8)	50.7 (28.9)	3.3 (4.1)	4.6 (2.8)	4.4 (2.6)	4.0 (4.0)	0.4 (0.4)	0.4 (0.3)	0.4 (0.4)	0.5 (0.6)	202.5 (130.0)	224.7 (131.4)	233.5 (132.6)	246.9 (132.5)
Sparse *Schima-Castanopsis* forests	4.7 (4.5)	1.3 (1.2)	4.6 (3.5)	1.3 (0.9)	4.5 (3.7)	1.2 (1.0)	5.0 (6.0)	1.4 (1.6)	76.0 (60.3)	20.7 (16.4)	79.4 (64.4)	21.6 (17.4)	74.5 (56.5)	20.3 (15.3)	83.4 (58.5)	22.7 (15.8)	1.2 (2.1)	3.1 (2.8)	3.3 (2.0)	2.2 (2.6)	0.4 (0.4)	0.5 (0.3)	0.5 (0.4)	0.5 (0.5)	102.8 (74.7)	110.5 (83.3)	117.7 (97.7)	115.1 (74.9)
Total *Schima-Castanopsis* forests	4.8 (3.9)	1.3 (1.1)	6.4 (5.0)	1.8 (1.4)	6.2 (5.3)	1.7 (1.4)	6.1 (5.6)	1.7 (1.5)	139.3 (99.9)	38.5 (27.9)	152.1 (102.8)	42.0 (28.6)	157.5 (104.3)	43.4 (28.9)	168.0 (104.5)	46.3 (29.1)	3.0 (3.9)	4.4 (2.8)	4.2 (2.6)	3.7 (3.9)	0.4 (0.4)	0.4 (0.3)	0.4 (0.4)	0.5 0.5)	187.0 (128.0)	207.0 (131.6)	215.5 (134.2)	226.5 (133.9)
Dense *Pine* forests	3.1 (5.2)	0.9 (1.5)	2.9 (3.6)	0.8 (1.0)	4.2 (5.3)	1.2 (1.5)	3.9 (5.7)	1.1 (1.6)	165.1 (94.9)	46.9 (28.0)	183.1 (93.0)	51.9 (27.4)	196.5 (91.1)	55.8 (26.9)	203.0 (90.0)	57.5 (26.6)	2.9 (3.8)	4.4 (3.5)	4.6 (3.2)	4.3 (4.4)	0.4 (0.4)	0.5 (0.4)	0.5 (0.4)	0.3 (0.4)	219.2 (120.7)	243.6 (120.5)	262.8 (116.9)	270.1 (115.5)
Sparse *Pine* forests	2.0 (2.2)	0.6 (0.6)	3.8 (4.1)	1.0 (1.1)	3.7 (3.2)	1.0 (0.9)	5.1 (4.9)	1.4 (1.4)	101.3 (79.2)	28.5 (23.9)	97.3 (75.2)	27.6 (22.8)	97.9 (76.4)	27.8 (23.1)	111.9 (77.6)	31.0 (23.3)	1.7 (2.2)	2.5 (2.9)	4.6 (2.4)	2.9 (3.3)	0.3 (0.3)	0.6 (0.4)	0.9 (0.5)	0.3 (0.3)	132.8 (102.8)	137.0 (98.6)	144.4 (105.2)	150.0 (98.9)

Total *Pine* forests	2.8 (4.5)	0.8 (1.3)	3.2 (3.8)	0.9 (1.0)	4.1 (4.7)	1.2 (1.4)	4.3 (5.4)	1.2 (1.5)	146.8 (94.4)	41.7 (27.9)	158.6 (95.8)	45.0 (28.1)	168.3 (97.3)	47.8 (28.6)	177.0 (95.3)	49.9 (28.2)	2.5 (3.4)	3.8 (3.4)	4.6 (3.0)	3.9 (4.1)	0.3 (0.3)	0.5 (0.4)	0.6 (0.5)	0.3 (0.4)	194.5 (121.3)	213.1 (123.5)	229.0 (124.7)	235.8 (122.8)
Dense *Rhododendron-Quercus* forests	6.3 (5.5)	1.9 (1.7)	7.5 (5.6)	2.2 (1.7)	6.8 (6.0)	2.0 (1.8)	7.2 (6.1)	2.2 (1.8)	177.6 (113.4)	52.9 (33.8)	185.8 (117.1)	55.4 (34.9)	183.9 (112.2)	54.8 (33.4)	187.6 (109.7)	55.9 (32.6)	4.8 (4.5)	5.9 (3.7)	4.9 (2.9)	5.5 (4.6)	0.5 (0.4)	0.4 (0.3)	0.3 (0.3)	0.5 (0.7)	244.1 (145.5)	257.1 (151.0)	252.9 (144.9)	258.9 (141.0)
Sparse *Rhododendron-Quercus* forests	5.0 (4.2)	1.5 (1.2)	5.4 (3.7)	1.6 (1.1)	7.0 (5.5)	2.1 (1.6)	7.8 (6.4)	2.3 (1.8)	74.4 (79.6)	21.3 (22.6)	71.5 (81.9)	20.4 (23.1)	70.6 (81.2)	20.2 (22.8)	79.3 (83.1)	22.6 (23.3)	0.2 (0.9)	4.3 (3.8)	2.6 (2.1)	3.0 (3.0)	0.3 (0.2)	0.3 (0.4)	0.2 (0.4)	0.2 (0.4)	102.7 (103.3)	103.5 (107.5)	102.7 (105.2)	115.3 (108.2)
Total *Rhododendron-Quercus* forests	6.1 (5.3)	1.8 (1.6)	7.1 (5.4)	2.1 (1.6)	6.9 (5.9)	2.0 91.8)	7.3 (6.1)	2.2 (1.8)	159.2 (114.7)	47.3 (34.2)	165.4 (119.6)	49.2 (35.6)	163.8 (115.4)	48.6 (34.3)	168.4 (112.9)	50.0 (33.6)	4.0 (4.5)	5.6 (3.7)	4.5 (2.9)	5.1 (4.4)	0.4 (0.4)	0.4 (0.3)	0.3 (0.3)	0.4 (0.6)	218.9 (148.7)	229.7 (155.2)	226.1 (149.7)	233.3 (146.0)
Total dense	5.0 (4.6)	1.4 (1.3)	6.1 (4.8)	1.7 (1.4)	5.6 (5.1)	1.6 (1.4)	5.5 (4.7)	1.5 (1.3)	184.1 (126.4)	51.0 (35.0)	198.0 (126.7)	54.8(35.1)	203.9 (124.2)	56.4 (34.3)	211.4 (123.1)	58.5 (34.0)	3.7 (4.0)	4.8 (2.9)	4.5 (2.7)	4.6 (3.9)	0.3 (0.4)	0.3 (0.3)	0.3 (0.3)	0.5 (0.5)	245.4 (160.7)	265.7 (161.1)	272.4 (158.0)	282.0 (156.3)
Total sparse	4.6 (4.3)	1.3 (1.2)	5.6 (4.6)	1.5 (1.3)	4.9 (3.8)	1.3 (1.1)	5.7 (5.2)	1.6 (1.4)	111.9 (90.5)	30.6 (24.7)	113.4 (93.0)	31.0 (25.4)	114.0 (89.7)	31.1 (24.5)	121.7 (87.4)	33.2 (23.9)	1.6 (2.3)	4.2 (3.0)	4.1 (2.4)	4.1 (3.5)	0.3 (0.3)	0.4 (0.3)	0.4 (0.4)	0.5 (0.5)	149.7 (115.7)	156.6 (119.1)	159.6 (117.3)	166.3 (112.3)
Total	4.9 (4.5)	1.4 (1.3)	6.0 (4.8)	1.7 (1.3)	5.5 (4.8)	1.5 (1.4)	5.5 (4.8)	1.5 (1.3)	170.1(123.5)	47.0 (34.2)	181.6 (125.4)	50.2 (34.7)	186.5 (123.5)	51.5 (34.1)	194.0 (122.3)	53.6 (33.8)	3.3 (3.8)	4.7 (3.0)	4.4 (2.6)	4.5 (3.9)	0.3 (0.3)	0.3 (0.3)	0.4 (0.3)	0.5 (0.5)	226.8 (157.6)	244.6 (159.7)	250.5 (157.3)	259.5 (155.6)

**AGSB- Above Ground Sapling Biomass, **BGSB-Below Ground Sapling Biomass, [#]AGTB- Above Ground Tree Biomass,[##] Below Ground Tree Biomass, N= number of plots*

Appendix G: Average carbon stock (MgC/ha) in individual CF in the study areas

CF name	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R	S	T	U
AamswaraBhawanipakha_G	9.1	4.2	4.9	0.0	0.0	0.0	0.0	891.7	950.6	964.5	999.0	59.0	13.8	34.5	6.5	1.5	3.8	11.7	97.6	3.9	1
Amalekharka_D	6.6	0.0	0.0	1.5	5.1	0.0	0.0	452.3	482.8	526.3	546.2	30.5	43.5	19.9	4.6	6.6	3.0	14.2	68.6	4.7	2
Badahare_G	25.8	10.7	15.1	0.0	0.0	0.0	0.0	2454.6	2616.5	2652.7	2748.9	161.9	36.2	96.2	6.3	1.4	3.7	11.4	95.2	3.8	1
Bagpani_G	68.2	67.6	0.6	0.0	0.0	0.0	0.0	8492.4	9067.6	9256.0	9549.5	575.2	188.5	293.5	8.4	2.8	4.3	15.5	124.6	5.2	1
Barshedadapari_D	35.4	0.0	0.0	11.6	23.8	0.0	0.0	2511.2	2723.9	2961.1	3085.3	212.7	237.2	124.1	6.0	6.7	3.5	16.2	70.9	5.4	3
Batauli_C	155.8	91.3	64.5	0.0	0.0	0.0	0.0	16193.5	17271.9	17553.7	18161.5	1078.4	281.9	607.8	6.9	1.8	3.9	12.6	104.0	4.2	1
BhageristanGhantari_G	5.2	3.2	2.1	0.0	0.0	0.0	0.0	548.7	585.3	595.0	615.5	36.6	9.7	20.5	7.0	1.8	3.9	12.7	104.8	4.2	1
Bhakare_D	104.4	0.0	0.0	76.3	28.2	0.0	0.0	8437.8	9654.2	10401.4	10974.0	1216.5	747.2	572.6	11.6	7.2	5.5	24.3	80.8	8.1	2
BhalukholaSoti_G	107.6	53.5	1.1	53.0	0.0	0.0	0.0	11403.1	12679.3	13224.1	13819.4	1276.2	544.8	595.3	11.9	5.1	5.5	22.5	106.0	7.5	2
Bhasmepakha_D	10.9	0.0	0.0	6.2	4.8	0.0	0.0	838.6	940.3	1016.5	1067.5	101.8	76.2	51.0	9.3	7.0	4.7	20.9	76.7	7.0	2
BhirmuniDevithan_D	6.0	0.0	0.0	0.0	6.0	0.0	0.0	376.3	384.8	422.7	434.0	8.4	37.9	11.3	1.4	6.3	1.9	9.6	62.9	3.2	4
Bhiteripakha_D	542.6	0.0	0.0	0.0	0.0	377.7	165.0	53620.1	55977.4	56192.6	57951.5	2357.4	215.1	1759.0	4.3	0.4	3.2	8.0	98.8	2.7	2
Bhumethan_D	46.7	0.0	0.0	15.9	30.0	0.8	0.0	3369.8	3663.1	3971.7	4139.1	293.3	308.6	167.5	6.3	6.6	3.6	16.5	72.2	5.5	4
Bichaur_D	47.7	0.0	0.0	7.3	40.4	0.0	0.0	3180.9	3350.4	3660.8	3787.1	169.5	310.4	126.3	3.6	6.5	2.6	12.7	66.7	4.2	2
Birenchok_G	83.6	69.9	13.7	0.0	0.0	0.0	0.0	9753.3	10410.1	10610.7	10957.6	656.8	200.5	347.0	7.9	2.4	4.2	14.4	116.7	4.8	1
Boldesetidevi_D	172.1	0.0	0.0	0.0	0.0	113.7	58.4	16673.4	17363.1	17432.0	17993.9	689.6	68.9	561.9	4.0	0.4	3.3	7.7	96.9	2.6	3
Budhabhimsen_D	42.0	0.0	0.0	9.1	32.9	0.0	0.0	2864.4	3051.5	3327.6	3452.0	187.1	276.1	124.4	4.5	6.6	3.0	14.0	68.2	4.7	2
Charnawati_D	819.4	0.0	0.0	0.0	73.6	733.7	12.1	90056.9	95444.6	96183.6	98597.9	5387.7	739.0	2414.4	6.6	0.9	2.9	10.4	109.9	3.5	2
Charnawati_DFasku	55.1	29.1	0.0	14.0	12.0	0.0	0.0	5620.6	6100.4	6361.9	6605.7	479.8	261.6	243.8	8.7	4.7	4.4	17.9	102.0	6.0	2
Chelibeti_C	64.8	59.6	6.2	0.0	0.0	0.0	0.0	7911.9	8446.2	8614.9	8892.6	534.2	168.7	277.7	8.2	2.6	4.3	15.1	122.1	5.0	1
Chisapani_G	50.0	45.2	4.9	0.0	0.0	0.0	0.0	6008.0	6413.6	6541.5	6752.5	405.6	127.9	211.0	8.1	2.6	4.2	14.9	120.1	5.0	1
Chitadhunda_D	51.5	0.0	0.0	0.0	51.5	0.0	0.0	3241.8	3314.5	3640.8	3738.4	72.7	326.3	97.7	1.4	6.3	1.9	9.6	62.9	3.2	4
Chitramkaminchu	313.9	19.2	14.5	213.7	66.5	0.0	0.0	26338.7	29961.7	32036.4	33748.5	3623.0	2074.7	1712.1	11.5	6.6	5.5	23.6	83.9	7.9	2

li_C																					
Chuchchedhunga_D	8.9	0.0	0.0	0.0	8.9	0.0	0.0	560.0	572.5	628.9	645.8	12.6	56.4	16.9	1.4	6.3	1.9	9.6	62.9	3.2	2
Chyanedada_D	64.9	0.0	0.0	0.0	0.0	33.1	31.8	5749.0	5915.8	5942.8	6161.1	166.8	27.0	218.3	2.6	0.4	3.4	6.4	88.6	2.1	2
ChyaseBhagawati_D	30.3	0.0	0.0	23.8	6.5	0.0	0.0	2490.9	2867.6	3086.4	3260.9	376.7	218.8	174.5	12.4	7.2	5.8	25.4	82.2	8.5	2
Deujar_C	278.9	52.2	85.3	131.7	9.5	0.0	0.0	24949.5	27840.3	29064.5	30487.0	2890.8	1224.2	1422.5	10.4	4.4	5.1	19.9	89.5	6.6	2
Devidhunda_C	189.1	152.0	36.1	0.0	0.0	0.0	0.0	21684.8	23143.4	23582.4	24358.1	1458.7	439.0	775.7	7.7	2.3	4.1	14.1	114.7	4.7	1
Devithan_D	43.9	0.0	0.0	14.4	29.6	0.0	0.0	3116.6	3379.9	3674.4	3828.2	263.3	294.5	153.8	6.0	6.7	3.5	16.2	70.9	5.4	2
Dhade_D	29.2	0.0	0.0	0.2	29.0	0.0	0.0	1840.5	1884.1	2069.1	2125.3	43.6	185.0	56.2	1.5	6.3	1.9	9.8	63.1	3.3	2
Dhadesinghadevi_D	343.7	0.0	0.0	0.0	0.0	229.5	114.2	33431.2	34831.9	34969.2	36089.7	1400.8	137.3	1120.5	4.1	0.4	3.3	7.7	97.3	2.6	4
Dharapani_C	147.1	142.2	5.0	0.0	0.0	0.0	0.0	18150.0	19378.2	19776.4	20406.5	1228.2	398.3	630.1	8.3	2.7	4.3	15.3	123.4	5.1	1
Dimal_D	38.2	0.0	0.0	33.2	3.5	1.5	0.0	3293.5	3821.2	4091.6	4328.7	527.7	270.4	237.1	13.8	7.1	6.2	27.1	86.2	9.0	3
Eklepakha_D	197.3	0.0	0.0	0.0	18.3	157.8	21.3	20663.9	21783.7	21967.1	22560.4	1119.8	183.4	593.3	5.7	0.9	3.0	9.6	104.7	3.2	2
GahateBaghkhor_D	5.5	0.0	0.0	0.2	5.4	0.0	0.0	353.3	363.8	399.1	410.5	10.5	35.3	11.4	1.9	6.4	2.1	10.3	63.7	3.4	2
GairiJungal_D	131.1	0.0	0.0	26.0	0.0	100.0	5.1	14124.6	15237.6	15470.1	15969.8	1113.0	232.5	499.7	8.5	1.8	3.8	14.1	107.7	4.7	2
Gangatepakha_G	173.6	156.8	13.2	0.0	3.7	0.0	0.0	20816.7	22212.7	22678.4	23405.7	1396.0	465.7	727.3	8.0	2.7	4.2	14.9	119.9	5.0	1
GhaledandaRanakhola_G	181.7	131.5	25.0	15.1	10.1	0.0	0.0	20249.5	21728.7	22282.0	23054.1	1479.2	553.3	772.1	8.1	3.0	4.3	15.4	111.5	5.1	2
Goldada_G	46.0	45.6	0.4	0.0	0.0	0.0	0.0	5733.3	6121.6	6248.9	6447.0	388.3	127.3	198.1	8.4	2.8	4.3	15.5	124.7	5.2	1
Golmeswor_D	215.2	0.0	0.0	101.0	114.2	0.0	0.0	16011.6	17730.5	19206.9	20110.8	1718.8	1476.5	903.8	8.0	6.9	4.2	19.1	74.4	6.4	3
Gothpani_D	23.5	0.0	0.0	17.4	6.1	0.0	0.0	1904.0	2181.1	2349.4	2479.4	277.1	168.3	130.0	11.8	7.2	5.5	24.5	81.0	8.2	3
Indreni_C	172.2	155.6	11.0	0.0	5.6	0.0	0.0	20622.4	22000.4	22474.0	23192.4	1377.9	473.6	718.4	8.0	2.8	4.2	14.9	119.8	5.0	1
Jamuna_C	34.5	10.9	23.7	0.0	0.0	0.0	0.0	3111.3	3315.2	3355.6	3481.0	203.9	40.4	125.3	5.9	1.2	3.6	10.7	90.1	3.6	1
Janapragati_C	118.8	97.2	21.7	0.0	0.0	0.0	0.0	13757.8	14683.6	14963.6	15454.8	925.8	280.0	491.2	7.8	2.4	4.1	14.3	115.8	4.8	1
Jharna_C	34.5	23.5	11.1	0.0	0.0	0.0	0.0	3755.1	4006.3	4076.4	4214.4	251.2	70.1	138.0	7.3	2.0	4.0	13.3	108.7	4.4	1
Jugedarkha_D	125.6	0.0	0.0	0.0	0.0	101.5	24.1	13181.0	13860.8	13909.1	14306.9	679.8	48.3	397.8	5.4	0.4	3.2	9.0	104.9	3.0	3
Jyamire_D	70.0	0.0	1.4	58.4	10.3	0.0	0.0	5850.0	6771.8	7272.8	7694.2	921.8	501.0	421.5	13.2	7.2	6.0	26.3	83.5	8.8	3

Kalchhe_D	21.5	3.4	0.0	13.0	5.1	0.0	0.0	1880.1	2116.1	2254.7	2367.3	236.0	138.7	112.6	11.0	6.5	5.2	22.7	87.5	7.6	3
Kalika_C	213.8	206.2	7.6	0.0	0.0	0.0	0.0	26342.3	28124.7	28702.3	29617.0	1782.5	577.6	914.7	8.3	2.7	4.3	15.3	123.2	5.1	1
Kamalamai_D	71.8	0.0	4.3	15.3	52.2	0.0	0.0	4942.2	5272.5	5718.9	5936.4	330.4	446.4	217.5	4.6	6.2	3.0	13.8	68.8	4.6	2
Kankali_C	91.6	78.5	13.1	0.0	0.0	0.0	0.0	10786.6	11513.6	11737.9	12120.0	727.0	224.3	382.2	7.9	2.4	4.2	14.6	117.8	4.9	1
Kharkandepakha_G	47.8	45.8	2.0	0.0	0.0	0.0	0.0	5878.5	6276.2	6404.7	6609.0	397.7	128.5	204.4	8.3	2.7	4.3	15.3	122.9	5.1	3
Kharkopakha_G	51.2	44.4	6.8	0.0	0.0	0.0	0.0	6050.2	6458.1	6584.5	6798.5	407.9	126.5	213.9	8.0	2.5	4.2	14.6	118.3	4.9	3
Kopila_D	96.1	0.0	0.0	88.2	7.8	0.0	0.0	8204.7	9577.4	10285.1	10900.6	1372.6	707.7	615.6	14.3	7.4	6.4	28.1	85.4	9.4	3
Kuprisalleri_D	42.0	0.0	0.0	1.6	40.4	0.0	0.0	2684.5	2766.3	3034.4	3122.0	81.9	268.0	87.6	1.9	6.4	2.1	10.4	63.9	3.5	3
Kuwadi_G	92.3	83.8	8.5	0.0	0.0	0.0	0.0	11105.0	11854.9	12091.9	12481.5	749.9	237.0	389.7	8.1	2.6	4.2	14.9	120.4	5.0	1
Kyamundanda_G	58.7	56.6	2.1	0.0	0.0	0.0	0.0	7235.5	7725.1	7883.7	8135.0	489.6	158.6	251.3	8.3	2.7	4.3	15.3	123.2	5.1	1
LaliGurans_D	35.5	0.0	0.0	10.3	25.2	0.0	0.0	2488.7	2683.7	2920.3	3038.4	194.9	236.7	118.1	5.5	6.7	3.3	15.5	70.1	5.2	2
Lamidanda_G	61.6	59.0	2.6	0.0	0.0	0.0	0.0	7569.5	8081.5	8247.0	8510.2	512.1	165.4	263.2	8.3	2.7	4.3	15.3	122.9	5.1	1
LaxmiMahila_G	8.7	8.1	0.6	0.0	0.0	0.0	0.0	1058.4	1129.9	1152.7	1189.7	71.5	22.8	37.0	8.2	2.6	4.2	15.1	121.3	5.0	1
Lodhini_D	50.7	0.0	0.0	46.6	4.0	0.0	0.0	4329.9	5055.2	5428.6	5753.7	725.4	373.4	325.2	14.3	7.4	6.4	28.1	85.5	9.4	2
Ludidamgade_G	270.7	221.4	44.1	0.0	5.2	0.0	0.0	31284.6	33376.5	34045.2	35156.8	2091.9	668.7	1111.6	7.7	2.5	4.1	14.3	115.6	4.8	1
Ludikhola_G	17.4	5.8	11.7	0.0	0.0	0.0	0.0	1584.9	1688.9	1709.9	1773.5	104.0	21.0	63.6	6.0	1.2	3.6	10.8	91.0	3.6	2
Mahabhir_D	50.3	0.0	0.0	33.1	2.3	14.9	0.0	4753.4	5375.3	5642.0	5917.0	621.9	266.7	275.0	12.4	5.3	5.5	23.2	94.6	7.7	2
MahakalSahele_D	39.4	0.0	0.0	26.7	12.7	0.0	0.0	3131.3	3561.0	3840.4	4046.2	429.7	279.4	205.8	10.9	7.1	5.2	23.2	79.5	7.7	3
Mahalaxmi_G	64.0	38.1	25.9	0.0	0.0	0.0	0.0	6678.4	7123.4	7240.4	7490.6	444.9	117.1	250.1	7.0	1.8	3.9	12.7	104.4	4.2	1
Maithan_D	28.3	0.0	0.0	3.5	24.9	0.0	0.0	1870.7	1959.9	2143.5	2214.5	89.2	183.6	71.0	3.1	6.5	2.5	12.1	66.0	4.0	2
MajhikholaSimrendanda_G	6.0	0.3	5.7	0.0	0.0	0.0	0.0	461.2	490.8	494.2	514.4	29.6	3.3	20.2	4.9	0.6	3.4	8.9	76.9	3.0	1
Majhkharka_lisepaniD	174.2	0.0	0.0	0.0	0.0	145.7	28.4	18550.4	19540.5	19606.9	20155.2	990.0	66.4	548.3	5.7	0.4	3.1	9.2	106.5	3.1	2
Mathani_D	28.3	0.0	0.0	22.5	5.8	0.0	0.0	2331.3	2687.0	2891.5	3055.7	355.6	204.5	164.3	12.6	7.2	5.8	25.6	82.4	8.5	2
Napkenmara_D	152.5	0.0	0.0	0.0	12.1	82.6	57.8	13803.5	14286.4	14420.5	14908.4	482.9	134.1	487.9	3.2	0.9	3.2	7.2	90.5	2.4	3
Nibuwatar_C	329.2	315.2	14.0	0.0	0.0	0.0	0.0	40455.6	43192.3	44076.5	45483.1	2736.8	884.2	1406.6	8.3	2.7	4.3	15.3	122.9	5.1	1
PalekoBan_D	1.5	0.0	0.0	0.0	0.0	1.0	0.5	146.2	152.7	153.3	158.1	6.4	0.6	4.8	4.3	0.4	3.2	8.0	98.5	2.7	4

PalungMahila_D	10.3	0.0	0.0	0.3	10.0	0.0	0.0	654.8	673.8	739.2	760.3	19.0	65.5	21.1	1.8	6.4	2.0	10.3	63.7	3.4	4
Patalchhape_G	8.2	7.4	0.7	0.0	0.0	0.0	0.0	983.8	1050.2	1071.3	1105.8	66.4	21.0	34.5	8.1	2.6	4.2	14.9	120.5	5.0	1
Pauwa_D	58.6	0.0	0.0	33.6	8.5	8.6	8.2	4956.1	5529.0	5840.1	6141.1	573.0	311.1	301.0	9.8	5.3	5.1	20.2	84.5	6.7	2
Pokhari_D	23.6	0.0	0.0	10.8	5.6	7.3	0.0	2128.9	2355.1	2473.4	2579.2	226.3	118.3	105.8	9.6	5.0	4.5	19.1	90.2	6.4	3
Pragati_C	115.5	70.8	44.7	0.0	0.0	0.0	0.0	12162.7	12973.7	13190.0	13643.7	811.0	216.3	453.7	7.0	1.9	3.9	12.8	105.3	4.3	1
Pungche_G	18.1	15.4	2.7	0.0	0.0	0.0	0.0	2130.2	2273.7	2317.9	2393.5	143.5	44.2	75.5	7.9	2.4	4.2	14.5	117.5	4.8	1
Ramite_D	13.6	0.0	0.0	13.2	0.4	0.0	0.0	1178.1	1381.9	1482.9	1573.3	203.8	100.9	90.5	15.0	7.4	6.7	29.1	86.6	9.7	2
RamLaxman_G	13.2	12.8	0.5	0.0	0.0	0.0	0.0	1633.1	1743.6	1779.4	1836.1	110.5	35.8	56.7	8.3	2.7	4.3	15.3	123.3	5.1	1
Salleri_D	92.3	0.0	0.0	26.7	65.6	0.0	0.0	6459.8	6964.2	7578.6	7884.6	504.4	614.4	306.0	5.5	6.7	3.3	15.4	70.0	5.1	2
Samfrang_C	63.9	26.8	37.1	0.0	0.0	0.0	0.0	6101.6	6504.2	6594.8	6833.5	402.6	90.6	238.7	6.3	1.4	3.7	11.5	95.5	3.8	1
SandanBisaune_G	50.6	48.7	2.0	0.0	0.0	0.0	0.0	6230.9	6652.5	6788.9	7005.4	421.6	136.4	216.5	8.3	2.7	4.3	15.3	123.1	5.1	2
Sankhadevi_D	305.3	0.0	0.0	0.0	0.0	247.4	57.9	32074.3	33733.2	33850.5	34816.8	1658.9	117.3	966.3	5.4	0.4	3.2	9.0	105.1	3.0	2
Sanobotle_D	35.1	0.0	0.0	0.0	0.0	18.3	16.8	3129.2	3223.1	3237.6	3355.4	93.9	14.6	117.7	2.7	0.4	3.4	6.5	89.3	2.2	2
Satkanya_C	58.3	56.0	2.3	0.0	0.0	0.0	0.0	7169.8	7654.9	7811.7	8060.9	485.1	156.9	249.2	8.3	2.7	4.3	15.3	123.0	5.1	1
Setidevi_D	421.7	0.0	0.0	0.0	0.0	192.6	229.1	36155.2	37026.5	37204.5	38638.4	871.4	177.9	1433.9	2.1	0.4	3.4	5.9	85.7	2.0	2
Shikhar_G	50.8	42.5	8.4	0.0	0.0	0.0	0.0	5932.1	6331.5	6453.4	6664.5	399.5	121.9	211.1	7.9	2.4	4.2	14.4	116.7	4.8	1
ShikharBarbhanjyang_G	55.5	55.4	0.0	0.0	0.0	0.0	0.0	6928.4	7397.8	7552.2	7791.3	469.4	154.3	239.1	8.5	2.8	4.3	15.5	124.8	5.2	1
Shikhardanda_G	30.3	16.3	14.1	0.0	0.0	0.0	0.0	3079.6	3284.2	3335.5	3452.5	204.6	51.4	117.0	6.7	1.7	3.9	12.3	101.5	4.1	1
Simpani_D	64.4	0.0	0.0	8.1	56.4	0.0	0.0	4249.8	4453.5	4870.5	5032.2	203.7	417.0	161.6	3.2	6.5	2.5	12.1	66.0	4.0	2
Simsungure_D	33.4	0.0	0.0	3.9	29.5	0.0	0.0	2192.9	2294.2	2509.7	2591.9	101.3	215.5	82.2	3.0	6.5	2.5	12.0	65.8	4.0	2
Siraute_G	60.3	56.2	4.1	0.0	0.0	0.0	0.0	7335.1	7830.9	7989.2	8245.5	495.7	158.3	256.3	8.2	2.6	4.2	15.1	121.6	5.0	2
Sitakunda_D	141.3	0.0	45.1	15.7	80.5	0.0	0.0	9779.6	10348.9	10995.1	11404.3	569.3	646.2	409.2	4.0	4.6	2.9	11.5	69.2	3.8	2
Sitalupakha_G	5.7	0.0	0.0	4.1	1.6	0.0	0.0	458.7	524.5	565.1	596.2	65.8	40.7	31.0	11.6	7.1	5.5	24.2	80.7	8.1	2
Srijana_D	264.2	0.0	0.0	0.0	0.0	209.9	54.3	27528.6	28924.1	29026.1	29865.2	1395.6	102.0	839.1	5.3	0.4	3.2	8.8	104.2	2.9	2
Sundarimai_D	13.0	0.0	0.0	4.5	8.5	0.0	0.0	927.2	1008.7	1096.0	1142.8	81.5	87.3	46.8	6.3	6.7	3.6	16.6	71.5	5.5	2
Taksartari_G	89.3	83.1	6.2	0.0	0.0	0.0	0.0	10851.6	11585.0	11819.1	12198.3	733.4	234.1	379.2	8.2	2.6	4.2	15.1	121.5	5.0	1
Thanhsadeurali_D	124.4	0.0	0.0	0.0	0.0	59.3	65.3	10811.2	11091.3	11143.6	11565.6	280.1	52.3	422.0	2.3	0.4	3.4	6.1	86.9	2.0	4

Tharlange_D	204.0	0.0	0.0	35.9	20.1	148.1	0.0	21487.8	23141.3	23589.6	24321.8	1653.5	448.4	732.2	8.1	2.2	3.6	13.9	105.3	4.6	2
Thoknebhanjyang _G	76.2	73.5	2.7	0.0	0.0	0.0	0.0	9393.3	10029.0	10235.0	10561.1	635.6	206.0	326.1	8.3	2.7	4.3	15.3	123.3	5.1	1
Thumkadada_D	40.8	0.0	0.0	0.0	0.0	20.6	20.2	3601.9	3704.6	3721.6	3859.0	102.7	17.0	137.4	2.5	0.4	3.4	6.3	88.3	2.1	3
Thutemane_D	23.6	0.0	0.0	0.0	2.1	8.6	12.9	1910.2	1946.1	1968.3	2046.3	35.9	22.2	78.0	1.5	0.9	3.3	5.8	81.0	1.9	4
TimureTinsale_D	67.1	0.0	0.0	23.5	43.6	0.0	0.0	4798.1	5222.1	5673.6	5916.2	424.0	451.5	242.6	6.3	6.7	3.6	16.7	71.5	5.6	4

Note:

A- Total area of community forests (ha)
B- Total area of forests in<1000m (≥70% canopy) (ha)
C-Total area of forests in <1000m (<70% canopy) (ha)
D-Total area of forests in 1000-2000m (≥70% canopy) (ha)
E-Total area of forests in 1000-2000m (<70% canopy) (ha)
F-Total area of forests in >2000m (≥70% canopy) (ha)
G-Total area of forests in <2000m (<70% canopy) (ha)
H-Total Carbon stock (Mg) in CF in 2010
I-Total Carbon stock (Mg) in CF in year 2011
J-Total Carbon stock (Mg) in CF in year 2012
K- Total Carbon stock (Mg) in CF in year 2013
L-Carbon stock change (Mg) in year 2010-2011
M- Carbon stock change (Mg) in year 2011-2012
N-Carbon stock change (Mg t) in year 2012-2013
O- Carbon stock change (MgC/ha) in CF in year 2010-2011
P- Carbon stock change (MgC/ha) in CF in year 2011-2012
Q-Carbon stock change (MgC/ha) in CF in year 2012-2013
R- Carbon stock change (MgC/ha) in CF in year 2010-2013
S- Carbon stock (MgC/ha) in 2010
T-Average annual stock change (MgC/ha) in CF

Appendix H: Summary of local practices, changes in CFs and local perceptions about REDD+ in the study areas

1. Status of forest before CFs

Most of the CFs in the mid-hills (*Schima-Castanopsis* forests, *Pine* forests) were degraded when legal community management activities started. Barren soil was visible from a distance due to the sparse canopy of the forests. Most of the large trees with cylindrical boles were gone. Management commenced with the collective decision of all members in CFs.

S. robusta and mixed broadleaf forests were comparatively better in terms of density; however, forests were treated as government property and local people were not taking care of them. They were collecting forest products illegally using haphazard practices. The government gave management authority of *S. robusta* forests to communities years later than was the case for higher and middle altitude forests. Moreover, settlements in areas surrounding *S. robusta* and mixed broadleaf forests of lower altitude areas have many newly migrated households (about 25–30 years). Therefore, they do not have established forest management practices compared to higher altitude forests.

2. Forest management practices of communities

According to communities, the key aims of forest management were to supply forest products for their own use, maintain forests for future generations and regulate rainfall. After community forestry practices commenced, they observed improved forests status and availability of forest products (firewood, fodder and grass). Now communities have good practices enabling the distribution of forest products in all CFs.

3. Benefits obtained from forests

In all CFs, there are provisions to facilitate income generating activities for poor members. These include a sustainable supply of forest products for their own use and raw materials for cottage industries. Handmade paper, essential oil distillation plants and beehive briquettes are the main interests in middle and high altitude CFs (*Schima-Castanopsis, Pine* and *Rhododendron-Quercus* forests). In lower altitude areas (*S. robusta* and mixed broad leaf), income from firewood and the sale of timber are main income streams. Possible income from ecosystem services including carbon sequestration is of increasing interest. Communities are willing to change their existing forest management and use practices to gain increasing carbon and non-carbon products if they get appropriate monetary benefits.

4. Decision making

Consensus building was the main approach for making decisions in CFs. In most CFs, the Chairman and Secretary call an executive committee meeting and provide an agenda, giving a chance for all participants to give their opinion, before arriving at a decision.

In a general assembly of the CFUG, the presence of all members is mandatory. The executive committee put out an agenda and take opinions from participants of the assembly to arrive at a decision. However, there is less chance to collect the opinions of communities due to time constraints particularly in terai (*S. robusta* and mixed broad leaf) where CFUG households are larger in numbers and more heterogeneous. However, mostly middle altitude CFUGs are small (by household numbers) and homogeneous; therefore, people have more chance to speak and include their voice in the decisions.

5. Preferred timber species

S. robusta is the preferred timber tree available in lower altitudes whereas *Schima-wallichi*, *Michelia*, *Pine* spp. and *Alnus nepalensis* are the main timber trees in middle and higher altitude areas. However, rich people of the hilly areas also use *S. robusta* timber brought from the terai region because it is comparatively durable; this is too expensive for poor people.

6. Source of forest products

CFs, private lands and leasehold forests (a patch of government forests handed to a group of poor households for the production of forest products, use and to generate income—e.g. fodder and grass production in leasehold forests for livestock is in practice in Kayerkhola watershed, Chitwan) are the main sources of forest products. CFs and leasehold forests were the main source in lower altitude terai (*S. robusta* and mixed broad leaf forests) whereas CFs and private land in hill areas (*Schima-Castanopsis*, *Pine* and *Rhododendron-Quercus* forests). In hilly regions, private land is less productive for agriculture and trees are grown in such lands. The collection of forest products from Government forests is limited because these forests are not in close to settlements. Timber products are generally obtained from the CFs and very little from private land. Timber extraction is only done for needy people after a decision of the executive committee of a CFUG.

7. Knowledge of REDD+ at communities

The majority of people were able to explain that the conservation of forests generates carbon and that will generate monetary benefits from carbon trading. They said the REDD+ is coming up and that they are implementing a pilot project which may not bring carbon money. However, they were happy to take initiatives for carbon enhancement in their forests as a trial. The level of understanding about REDD+ increased in all CFs after project activities.

8. Key changes made for REDD+

Communities have changed their existing forest product use behaviours for the REDD+. The main behaviours were:

- Most of CFUGs have reduced timber and green tree harvest in forests
- They have made more systematic and careful collection of grasses and fodder to reduce possible damages

- They have not reduced NTFP income but have tried to promote this in a sustainable way
- Decisions were made in executive committee meetings and assemblies. The numbers of meetings increased for REDD+
- Additional efforts were made for silviculture operations, guarding against illegal harvesting and fire control activities.
- Plantations on non-arable private lands and sparse areas in CFs has increased
- Reduced grazing in CFs
- Reduced numbers of livestock in some CFs

9. Perspective benefits of REDD+

Improvement of forests, sustainable supply of forest products and monetary benefit for CFUGs for use in development activities such as road, school, community building and alternative energy (improved cooking stock, biogass, solar) promotion etc. REDD+ carbon money can also be used for income generation activities particularly for poor.

10. Suggestions for making the REDD+ project effective in CFs

- Encourage all members by proving adequate knowledge of the REDD+
- Compensate/ benefit all users with priority to poor users
- Provide alternatives for household energy needs
- Provide alternative income sources that help to reduce livestock number therefore reduce fodder and grass requirements
- Institutional setup to ensure the flow of carbon benefits and trade

11. Opinion about biomass quantity in proximity of forests from settlement and road head

In lowland terai, forests located close to a roadhead have high levels of illegal harvesting activity and may have less biomass whereas in the hills, this is not the case. In a majority of forests located close to a settlement, there is more care and people do not engage in illegal activities in that area; therefore biomass growth can be higher. However, lower altitude *S. robusta* forests and broadleaf forests had heterogeneous communities and comparatively new settlements which may have led to some extraction going on.

Appendix I: Definition of some terms used in this thesis

Bhari	A load that an adult male/female carries on his/her back. An average Bhari of fuelwood is 30 kg, Bhari of fodder is 25 kg, average Bhari of litter is 20 kg
Caste	A form of social stratification characterized by hereditary transmission which may involve different occupations and beliefs
Co-benefits/non-carbon benefits	Benefits arising from REDD schemes (other than reducing GHG emissions), such as alleviating poverty, protecting environment, enhancing biodiversity, improving forest governance and protecting human rights
Community forestry	Forest management model in which a national forest handed over to an user group for its development, conservation and utilization for the collective interest following forest policy provisions
Current annual increment (CAI)	Growth observed in a stand in a specific one year period
Forest ecosystem services	Multiple benefits that a forest can provide to human being. It includes provisioning services such as food, raw material, medicine, genetic resources, biodiversity etc; regulating services such carbon sequestration, water/air purification; and cultural services such as recreational and historical value. In this study ecosystem services refers other ecosystem services than carbon sequestration
Leakage	Displaced emissions from REDD+ project area
Livestock unit (LU)	A way of comparing the nutritional requirements of grazing animals. Equivalent of 1Buffalo=1, 1 Cow=0.7, and 1 Goat=0.1
Maximum sustained yield (MSY)	This is theoretically largest yield that can be taken from a species stock over a long period
Mean annual increment (MAI)	Average growth per year a stand of trees has exhibited to a specified age

Non-permanence	The risks that carbon removals are reversed after the credits have been created
REDD+	A likely incentive mechanism for reducing emissions from deforestation and forest degradation, conservation, sustainable management of forests and enhancement of forest carbon stock in developing countries
Sustained yield	The amount of a resource obtained from such a schedule without depleting the resources