Regeneration of *Shorea robusta* and *Schima wallichii* under Community Forest Management in Ludikhola watershed, Gorkha district, Nepal

Master Thesis in Environment and Landscape Geography

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Front page pictures:

Background: A view of the forest landscape in Ludikhola.

Inserted pictures, from left: Fodder collection in Taksartari; the Community Forest User Group in Mahalaxmi, who had called for a forest meeting; children in Taksartari eager to show off the goat kids.

Fieldwork, spring 2012.

ABSTRACT

Resource and forest management in Nepal: Resource management is of current global interest because of its role in sustaining natural resources and livelihood for future generations. Hardin's paper, the "Tragedy of the Commons", served as a starting point to the wider discussion on challenges for sustainable resource management. Hardin's theory is widely cited in the context of forest management, especially to explain forest degradation, e.g. in the Himalaya where forest degradation has a long history. During the 1950s–1970s it became increasingly difficult to ignore the warnings of severe on-going deforestation in Nepal. Forests were nationalized and owned by the state and they were poorly, if at all, managed. In practice they were therefore 'commons' in the way that Hardin used the concept; an area of open access resources for anybody to use. The precarious situation pushed forth the formation of institutions and policies that aimed to secure forest sustainability by regulating forest-product outtake. Community Forestry (CF) management was introduced in the late 1970s. Rights to use forests were decentralized from top-down governmental management to bottom-up management by means of locally-run Community Forests (CFs).

Theories, aims and hypotheses: Deforestation and forest degradation have shifted towards a stable or a growing forest cover in several areas. Contrary to Hardin's argument that 'commons' will be depleted if not managed by a public government system or private land tenure, Ostrom argues that communities are capable of managing resources in sustainable ways by self-regulating practices and social check-ups. I hypothesise that her argument is valid with changes in underlying human-ecological factors such as forest user-density and market proximity, i.e. I assume that forests can regenerate sustainably independently of the number of users per forest area, distance to the urban centre and the main district road. I test this by analysing the regeneration of *Shorea robusta* and *Schima wallichii* in six CFs located in Ludikhola watershed, Gorkha district, Nepal. The close located forests were heavily degraded when CF management was established *c* 30 years ago.

Methods: I combined results from systematic forest sampling and interviews to determine if forest regeneration is sustainable under the current management regime. Physical and biological features were analysed in a total of 90 plots (10m×10m) in a balanced design. Recruits were counted, and DBH of trees measured. I used univariate and multivariate statistics to analyse the quantitative data, whereas qualitative data were used to contextualize numerical results.

Major results and conclusions: The CFs are regenerating in a sustainable manner. This is shown by reversed J-shaped size-class distributions and sufficient number of recruits. The environmental variables with the greatest impact on recruits indicate that both species are prone to disturbances related to land-use. *Shorea robusta* recruits decrease with denser canopy closure and more leaf litter on the ground. The intensity of lopping does not influence the number of recruits, but decreases seedling abundance; and number of recruits decreases in areas where many stems were cut. Environmental variables with an impact on *Schima wallichii* recruits are fewer, and the environmental variable that explains most of the variability within *Schima wallichii* recruits is degree of lopping. Highly lopped plots have the greatest abundance of *Schima wallichii*, interpreted as the response to decreased competition from the dominant, but more heavily lopped *Shorea robusta.* Differences in terms of the human-ecological variables, changing user-density and distance to Gorkha between the forests do not create any regenerative pattern in the abundance of recruits of either species. These findings support Ostrom's argument that locally initiated CF management may regulate forest-product outtake sustainably. Overall results indicate that CF has been successful in sustaining and even improving forest resources in the Ludikhola watershed the last decades.

Keywords: Forest regeneration; deforestation; forest management; Community Forestry; human impact; sub-temperate forests; *Shorea robusta*; *Schima wallichii*; Gorkha; Nepal.

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As I go along I hope it's true that I *"(...)will find something more in woods than in books. Trees and stones will teach you that which you can never learn from masters"* (Saint Bernard).

Kristin Madsen Klokkeide

Kristin Madsen Klokkeide,
Bergen, May 2013.

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ACRONYMS AND ABBREVIATIONS

CF	Community Forest or Community Forestry
CFUG	Community Forest User Group
DBH	Diameter at breast height
DFO	District Forest Office
HDI	Human Development Index
Masl	Metres above sea level
MAT	Mean Annual Temperature
OP	Operational Plan
RRI	Relative Radiation Index
NTFP	Non-timber forest product
REDD	Reduced Emission from reduced Deforestation and Degradation
$REDD^+$	Reduced Emission from reduced Deforestation and Degradation in Developing Countries
THED	The Theory of Himalayan Degradation

CHAPTER 1 INTRODUCTION

Most of today's land areas and ecological systems are influenced by humans (Ostrom & Nagendra 2006). They have become "anthromes"; 'natural biomes transformed by humans over the last 300 years, where many wilderness areas have become anthropogenic ones (Ellis et al. 2010), including forests. Understanding such systems therefore depends on linking biophysical aspects to human use as these rarely exist isolated from each other (Ostrom & Nagendra 2006). This implies acknowledging that forest resources are crucial for human livelihoods, and that sustainable resource management is a pathway to protect forests, at the same time as human needs are sustained.

Forests currently cover 31 % (4 billion hectares (ha)) of the world's total land area (Food and Agriculture Organization of the United Nations FAO 2011) and more than 1.6 billion people depend on them for sustaining their livelihoods (United Nations 2011). Forest ecosystems are essential in providing resources such as fuelwood, food, fibre and fodder for domestic animals, and they are particularly important in agroforestry systems, such as in Nepal (Aase & Vetaas 2007). The forest cover in Nepal was 3 636 000 ha, equivalent to 25 % of the total land area, in 2010. It consisted almost exclusively of either primary forests (14 %) or naturally regenerated secondary forests (84 %) (FAO 2010a). Most people depend on subsistence agriculture for their survival and Nepal is one of the world's poorest and least developed countries (Central Intelligence Agency CIA 2013), ranked as country number 157 of 186 on the Human Development Index (HDI) by United Nations Development Programme (UNDP 2013). By 2011 a total of 83 % of the human population lived in rural areas (Central Bureau of Statistics CBS 2012) and accordingly, more than 75 and 40 % of the energy resources and the fodder needs, respectively, were met by forests (HMG/ADB/FINNIDA 1988 in Chaudhary 2000).

1.1 Human population growth, deforestation and regeneration

Deforestation; the conversion of forest to other land-uses, or long-term reduction of the tree canopy cover below the minimum 10 % threshold (FAO 2010b) has led to immense forest net losses. Estimations show that *c* 555 million ha forest have disappeared during the last half century (Williams 2006). In only the last 10 years the FAO (2010a) estimates that 5.2 million ha forest has been lost. The rate of deforestation has throughout history varied in time and geographical space. Until the 20th Century deforestation was most severe in temperate forests in Asia, North-

America and Europe where forests were cleared to release land for agricultural production and to obtain raw materials. Over the last century deforestation has mainly shifted to tropical forests, often situated in areas where humans are highly dependent on products from the land (FAO 2012).

The extensive deforestation and the alarming rate at which forests are disappearing have gradually been recognized in recent decades. There are strong relationships between forest use and economic and social development, as well as between destruction of forests and economic decline (FAO 2012). Emphasis has therefore been directed towards forest ecosystem management (Millennium Ecosystem Assessment 2005) and attention brought to forests worldwide (FAO 2010a) by events such as “The International Year of Forests” designated in 2011 by the United Nations General Assembly (FAO 2011). The recent focus on sustainable forest management reflects the importance of forests for sustaining human livelihoods and their crucial role in carbon and climate mitigation strategies (Nabuurs et al. 2007). Protecting, managing, restoring, recreating and creating forests has been put on the agenda as a result of multiple motivations people have in using and sustaining forests (Putz & Redford 2010) .

Since the 1800s forests have disappeared almost proportionally with the human population. More people demand more food, fibre and fuel, which in turn creates a marked association between population growth and high rates of deforestation (FAO 2010a; 2012). The forest history of Southern Asia reflects the global deforestation trends and the subsequent urge to manage forests. According to the FAO (2012) half of the historically forested areas have been cleared to release agricultural land for the growing human population during the last 500 years and deforestation has a long history in Nepal. According to Mahat et al. (1986) forests have been disappearing from the middle of the 18^{th} Century although it was during the last half of the 20^{th} Century that deforestation became severe and the rate at which forests were disappearing non-sustainable. According to Mahat, this precarious situation resulted from a period with weak ministries and a lack of forest regulation in the early 1950s and 1960s (Mahat et al. 1986). This period was also characterized by high population growth. From 1952/4 until 2001 the annual population growth rate exceeded 2.2 %. This comprised a net gain of people from *c* 8 million to 26 million (CBS 2012). Concurrent with this, the annual forest cover declined by 2.1 % and 1.4 % between 1990-2000 and 2000-2005, respectively (FAO 2010a).

Eckholm's (1975) doomsday prophecies in "The Deterioration of Mountain Environments" was one of the first serious calls for action. He described how ecological stress, caused and pushed by human population growth led to "a widening circle of denuded hillsides" and it was reckoned that "the pace of destruction is reaching unignorable proportions" (Eckholm 1975 pp 764-765). These perceptions made up a narrative that Ives and Messerli (1989 in Guthman 1997) termed "The Theory of Himalayan Degradation" (THED). Influenced by this story, the World Bank (1979 p 30) stated that "demands on the forests are well beyond sustainable levels and recent studies indicate that continued encroachment into forests is inevitable. Without large scale afforestation programs, the accessible forests in the Hills will have largely disappeared by 1990 and those in the Terai by the year 2000". Although THED was later criticized, among others by Ives (2004 p 17) who saw it as "a dangerous collection of assumptions and misrepresentations" that lacked scientific substantiation and validation, this narrative became important in framing how the on-going environmental degradation was perceived. The high population growth from the 1950s up to now supported the narrative and did not plead Ives' case. Present literature generally accepts that Eckholm's (1975) prophecies were exaggerations of the extent of forest degradation, and predictions such as that from the World Bank of 1979, have obviously been rejected. Some authors even argue that deforestation in certain areas of the Middle Hills did not occur at all (see e.g. Byers 1987 comparative results of forest condition in 1962 vs. 1984 from Khumbu region).

There is recent evidence that deforestation and loss of natural resources have slowed down globally (FAO 2010a; 2011). This is also true for Nepal where, despite an annual population increase of 1.35 % in 2011 (CBS 2012), no annual change in the forest cover was found between 2005 and 2010 (FAO 2010a). It has also been argued that the local environmental conditions in some areas of Nepal have improved during the last decades (Gautam et al. 2002; Dev et al. 2003; Nagendra 2007; Nagendra et al. 2008a; Tachibana & Adhikari 2009; Pandit & Bevilacqua 2011). The positive trends may relate to significant progress in the development of forest policies, laws and national forest programmes worldwide. Despite these positive indications, particularly related to forest regrowth in some temperate and boreal zones, the global rate of deforestation is still alarmingly high (FAO 2011).

1.2 Common-pool resource management and Community Forestry (CF)

Because forests in Nepal always have been "(…)inextricably interwoven with other land uses and with political, social, demographic, and economic change" (Mahat et al. 1986 p 224) forest management, especially common-pool resource management, has been recognized as a key component for obtaining sustainable land-use systems by. Despite THED having been falsified it had a great influence on policy formation and on developing the environmental sector in Nepal (Pokharel et al. 2007). The claim that environmental stress was caused by accelerating human population growth provided the impetus to begin regulating forests, and a Community Forestry (CF) policy was implemented by the late 1970s (Mahat et al. 1986; Acharya 2002; Gautam et al. 2004).

CF management involves handing over rights to use and obligations to conserve forests to villagers. Use is regulated through the Operational Plan (OP) of each Community Forest User Group (CFUG), i.e. groups legally recognized for managing forests. The OP is approved by the District Forest Office (DFO) on behalf of the forest owner, the government. Decentralized CF management allows villagers to use forests according to their own rules (Blaikie & Springate-Baginski 2007) and I will use the term 'user right' (see e.g. Adhikari et al. (2004a)) for the management agreement between villagers organized in CFUGs and the DFO. Up until recently, user rights have been decentralized and allocated to communities in 33 % of Nepal's national forest areas (FAO 2011), and increasing forest cover is a success linked to the CF management regime on several occasions (e.g. Nagendra et al. 2005; Nagendra 2007).

1.3 Study relevance

Several authors (Gautam et al. 2002; Dev et al. 2003; Adhikari et al. 2007; Thoms 2008; Tachibana & Adhikari 2009; Pandit & Bevilacqua 2011) support the view that CF has been successful in regulating and sustaining forest resources in various respects. These findings contrast the senarios one may expect from Hardin's (1968) argument in the "Tradgedy of the Commons". Hardin argued that 'commons', i.e. areas not regulated by anyone specific, would be overharvested if not controlled either by a public government system, or a private land tenure. This theory is based on the assumption that users of 'commons' are not likely to coordinate their use practices internally. When no external management system exists, rational users are likely to maximize their personal gain as they expect others to do the same. Maximizing one's own gain gives a net positive utility close to +1 as benefits from the additional resource is not shared; while negative utlities are shared by all those who use the resource, meaning that the utility per user is only a fraction of –1. The sensible choice of any single user is therefore to maximize output from 'commons'; and the result is that "Freedom in a commons brings ruin to all" (Hardin 1968 p 1244). This implies that if one person uses a resource in a sustainable manner, that person will be "the loser" as his/her net output will be the smallest and the resource degraded by the unsustainable use of the others.

Ostrom is perhaps the most prominent writer to challenge Hardin's presumption that a single governance arrangement will control overharvesting in all settings (Ostrom et al. 1994; Ostrom 1999; Ostrom & Nagendra 2006). Ostrom and Nagendra (2006) show that engaging users in decisions that affect themselves, increases the likelihood for them to follow-up on the rules, as well as to monitor others to follow them. Rules that have been formulated by the users themselves perform better than rules imposed on them by an authority. Ostrom and Nagendra therefore argue that CF can be as effective, if not more effective, than public management in sustaining resources, and several other researchers agree that CF management has the ability to improve the local environment and thereby forest conditions (Varughese & Ostrom 2001; Gautam et al. 2002; Dev et al. 2003; Ostrom & Nagendra 2006; Nagendra et al. 2008b; Tachibana & Adhikari 2009; Pandit & Bevilacqua 2011).

This thesis aims to contrast the views of Hardin with Ostrom's rationale: the presumption that CF management can prevent overharvesting by local monitoring and internal social check-ups, in the context of a sub-tropical agroforestry system in Nepal. I will assess if this rationale is valid with changing human-ecological gradients (forest user-density and market proximity), and I seek to test this by the ability of forest regeneration. If Ostrom's rationale holds true, these factors will not determine forest regeneration as the management system will overrule people's wish to maximize their personal gain and regulate forest-product outtake. The characteristic of Nepal as one of the forerunners of CF management (Varughese & Ostrom 2001; Ostrom & Nagendra 2006) makes it an especially interesting study area for assessing if human-ecological factors determine forest regeneration.

The success of CF management is typically described through achievements in forest conditions and by communities socio-economic improvements, with the former point of view being understudied compared to the latter. More research that focuses directly on forest health and forest regeneration is therefore needed to understand the complexities of the field. I therefore elucidate the links between CF management, which should ensure sustainable use of forests, and concepts such as outtake of biomass, sustainable and non-sustainable management, degradation and regeneration in this thesis. I focus on the response to intensity of use of two forest-forming tree species: *Shorea robusta*, the main canopy dominant, and its associated sub-species *Schima wallichii*. As these are the main 'forest'/'canopy' forming species, it is the regeneration of these I refer to when I use the expression "forest regeneration" or "forest's regenerative capacities". The studied forests, which were heavily exploited and consequently deforested at the time when local management was introduced around 30 years ago, are located in Ludikhola watershed in the Gorkha district of Nepal.

1.4 Main aim

This study aims to explore if CFs in Ludikhola watershed are sustainably managed. I want to explore if land-use practises (i.e. anthropogenic disturbance) are decisive for the forest's regeneration and define if they are sustainable, that is, regenerating under the current utilization and management regime. I will address my aim by answering and testing the following research questions and hypotheses by quantitative and qualitative research methods.

1.5 Research questions

The aim was addressed by exploring the regeneration of populations of *Shorea robusta* Gaertn.f. (hereafter called *Shorea*) and *Schima wallichii* (DC.) Korth (hereafter called *Schima*) along two human-ecological gradients (i.e. anthropogenic disturbance gradients). One gradient is simply the distance in kilometres and the time it takes to walk to the nearest urban centre (district headquarters: Gorkha), and the other is the forest user-density, i.e. number of households that are eligible to use the different CFs calculated as number of households (Hh) per CF hectare: $^{(Hh)}/_{(Ha)}$.

The following research questions were addressed:

- Is regeneration of *Shorea* and *Schima* sustainable in the studied forests under the current disturbance regimes?
- Is regeneration of *Shorea* and *Schima* sustainable by locally initiated CF management, independent of human-ecological factors such as forest user-density and geographical and walking distance to Gorkha?
- How do forest user-density and geographical distance relate to the regeneration of the target species?
- What are the impacts of the locally initiated CF management on population patterns and regenerative capacities of the target species'?

1.6 Hypotheses, logical assumptions and premises

The research questions were answered by testing the following hypothesis:

H_0: Forest user-density and geographical distance do not affect forests' regenerative capacities.

H_1: Forest user-density impacts forests' regenerative capacities.

H_2: Geographical distance impacts forests' regenerative capacities.

H_3: Interactions of forest user-density and geographical distance impact forests' regenerative capacities.

The underpinning assumptions for these hypotheses are as follows:

- More households → use more forest products → impose greater forest disturbances, *and* vice versa
- Longer distances to the market → increased forest dependency because of market "inaccessibility" → greater forest disturbances, *and* vice versa

These assumptions are based on the following premises between the land-use related explanatory variables:

- We expect canopy closure to be high where there are many trees. This is based on the premise that lopping and cutting of trees is not carried out intensively and uniformly throughout the forests.

- Ground litter cover increases when canopy closure increases. This is based on the premise that collection of leaf litter for e.g. mulching is not carried out intensively and uniformly throughout the forests.
- Degree of lopping and number of cut stems are highly related expressions of forest disturbance. They are, however, not decisive for regenerative capacities alone.

The formal numerical model is:

$$Y = a + bx_1 + cx_2 + dx_3 + e,$$

where *a, b, c, d* are constants/parameters estimated from the observed data that describe the effects of the explanatory variables: x_1 = average households per CF area; x_2 = distance to Gorkha bazar; $dx_3 = x_1 \times x_2$ on the response variable, Y. The random/error component is captured in *e*. Residuals of significant regressions were assessed with respect to normality and spatial autocorrelation.

1.7 Variables: forest response to explanatory variables and co-variables

The research questions are approached by analyses of interactions between response and explanatory variables and co-variables. The principal response variables are seedlings, saplings, seedlings + saplings, recruits, and trees of *Shorea* and *Schima*. I am interested in the effects of land-use related explanatory variables on these response variables.

Explanatory variables are influenced by the land-use system and hence part of the causal link between utilization of forests and forest sustainability. I assigned forest user-density and distance to Gorkha to be the prime explanatory variables (H_1-H_3). Canopy closure, ground litter cover, degree of lopping, number of cut stems and fire are explanatory factors that per definition are related to land-use intensity, and hence have direct influence on the response variables.

Factors that may affect response variables that are not influenced by the land-use system are defined as co-variables. The physical co-variables are Relative Radiation Index (RRI), elevation (masl) and soil moisture, while the presence of *Eupatorium odoratum* (*E. oduratum*) or *Eupatorium adenophorum* (*E. adenophorum*) is a biological co-variable.

1.8 Thesis structure

I continue this chapter by introducing some core concepts in a conceptual framework. I present the terms in the respect which I will use them throughout the thesis.

Chapter 2 presents the study area in various respects (location, geomorphological setting, climatic conditions and vegetation). I start at the country level and I narrow the description down to concern the specific field area. The second part of this chapter focuses directly on subsistence agriculture, the contextualising land-use system of this study.

Chapter 3 concerns the methodological framework. The chapter is divided into three major sections. I start with the procedure of locating the study area and then I explain the plot measurement variables. The third section, the analytical path shows how I have used the quantitative and the qualitative data collected during fieldwork.

Chapter 4 is the result chapter. It is structured by the analytical path. Figures and tables are central in depicting and explaining findings of this study. I start off by descriptive statistics and continue to internal correlations. I then look at the influences on the response variables by explanatory variables by regression and multiple regression analyses. Finally I consider the effects of the hypothesis variables on forest regeneration. I end the chapter by summing up the main qualitative findings from CFUG interviews.

In the discussion, chapter 5, I contextualize and synthesize quantitative data with qualitative interpretations. I am especially concerned with the effects of disturbance on regeneration, and with the management implications of CF.

I conclude in chapter 6 by summing up the major findings. I point at important aspects of future common-pool resource management, and I propose fields of research which may enhance our future understanding of regeneration- and management dynamics.

1.9 Conceptual framework

1.9.1 Forest

The lack of a common definition of what is meant by 'forest' creates an ambiguity in the forest literature that it is important to be aware of. Various stakeholders are driven by various concerns and motivations: their efforts might be on protection, management, restoring or recreating forests. The multiple ways in which 'forests' are defined result in legal and practical implications (Putz & Redford 2010). One definition can hardly cover *and* appropriately represent *all* motivations at *all* scales. On this basis it becomes clear that in studies of forests it is essential to be familiar with the applied definition and preferably also the motivations for each specific study.

The Food and Agriculture Organization of the United Nations (FAO 2000) defines 'forest' as land of at least 0.5 ha not primarily under agricultural or urban land-use with a tree canopy cover of at least 10 %. Trees should be able to reach at least 5 m *in situ*. Forests are sub-divided in 'open' – tree canopy cover 10-30 %, and 'closed' – tree canopy cover >40 %.

The International Forestry Resources and Institutions (IFRI), a research network initiated and coordinated by Elinor Ostrom and currently Arun Agrawal, that focuses on the effects of governance arrangements on people and forests (IFRI 2013) sought to include agroforestry woodlots and human use of forests in their working definition. An 'IFRI forest' is therefore an area that consists of woody vegetation (trees, bushes, shrubs) of at least 0.5 ha. The woody area must be exploited by at least three households and the forest shall be governed by a similar legal structure (Ostrom 2008).

'Kyoto forest' has become a term for the definition of forest applied in the United Nations Framework Convention on Climate Change (UNFCCC). UNFCC's approach allows countries, within certain parameters, to define what is meant by 'forest'. The minimum requirements for a forest to be defined as a 'Kyoto forest' is that it is 0.01-1.0 ha; has a canopy cover between 10-30 %; and that the minimum tree height is 2-5 m (Lambrechts et al. 2009).

A contrasting way of characterizing vegetation is given by Jennings et al. (2009, in Putz & Redford 2010). They range vegetation along a continuum from treeless to dense forest. Of interest here are 'woodlands'; characterized by graminoids in the understorey and a tree crown cover between 20-40 %; 'open forest' characterized by a crown cover between 40-70 %; and 'closed forests' with more than 70 % tree crown cover. Jenning et al.'s characterization contrasts that of the FAO by the considerably higher crown cover threshold required to be defined as a 'forest'.

1.9.2 Disturbance

The term disturbance, although recognized as an important component of many natural ecosystems (Hobbs & Huenneke 1992), has been used inconsistently in ecology. The need for a coherent definition of the ecological meaning of disturbance was set on the agenda in the late 1970s (e.g. Grime 1979; Pickett & White 1985; Rykiel 1985). The broad definition by Pickett and White (1985 p 7) of disturbance as "(…)any relatively discrete event in time that disrupts ecosystem, community, or population structure and changes recourses, substrate availability, or the physical environment" serves as a general basis for the use of the concept.

Disturbances may be natural (Putz & Canham 1992; Turner et al. 2003) or anthropogenic (Sarmiento 1997; Turner et al. 2003; Acácio et al. 2007). Depending on the immediate effects and the following consequences of disturbance it can be perceived positively or negatively. Sousa and Tilman (1984; 1985 in van der Maarel 1993) e.g. focus on the positive effects by disturbance on species survival as it releases resources that enables their survival.

One of the common approaches to disturbance is discussing it in terms of stability and diversity (Pickett & White 1985; Rykiel 1985; van der Maarel 1993). Rykiel (1985 p 363) expresses that the strong linkage between disturbance and stability with the statement that "(…)stability has no intrinsic meaning without reference to a disturbance(…)". In this thesis I draw upon disturbances articulated and imposed by the human use of forests and forests resources. This means I understand 'disturbance' as it is used in ecology as a metaphor equivalent to 'human uses of forests' as use/silviculture have many mechanisms in common with disturbance. The forest utilization I am concerned with is reflected in Grime's (1979 p 39) definition of disturbance as "(…)the mechanisms which limit the plant biomass by causing its partial or complete destruction". This conceptualization defines possible consequences on plants by disturbance in the form of removing biomass. I am interested in the influences that human-induced disturbances (Figure 1.1) such as lopping and logging have on target species; and I study regeneration from the perspective that different intensities of disturbance might render a forest sustainable or non-sustainable.

Biomass outtake such as lopping or cutting saplings for firewood are examples of disturbances/re-set mechanisms of an anthropogenic nature that may slow down or hinder a forest to grow into an old stand-structure because they limit its ability to regenerate by natural means. Putz and Canham (1992) used the term ‘arrested succession’ for the understanding of disturbance as a mechanism that re-sets succession by delaying, stopping or ‘arresting’ it. The long-term effects of persistent disturbances are unknown, but Singh (1998) uses the term ‘chronic’ disturbance to describe the effects persistent biomass outtake might have on forests over time. He argues that even a biomass outtake that *per se* is within the initial forest carrying capacity might be critical as the persistency of the outtake leaves the forest with inadequate time to recover. Over time, undefined and ‘unnoticeable’ disturbances might be equally destructive as the visible, ‘acute’ disturbances (Singh 1998) described by Grime (1979), for example.

1.9.3 Forest regeneration

Forest regeneration is defined as “The renewal of a stand of trees through either natural means (seeded on-site or adjacent stands or deposited by wind, birds, or animals) or artificial means (by planting seedlings or direct seeding)” (Intergovernmental Panel on Climate Change IPCC 2000 p 26). The FAO (2008) defined a set of essential key components for achieving sustainable forest management and introduced decentralized management of forests to secure sustainability of resource use. The content of what ‘sustainability’ in management of forests implies is, however, by some means, indefinite. I will not elucidate the term ‘sustainable development’ as it was used by the Brundtland Commission (1987) for this purpose: I will instead turn to these key components defined by the FAO (2008):

- *Extent of forest resources:* Forest cover and stocking is significant.
- *Biological diversity:* Biological diversity shall be managed and conserved at ecosystem, species and genetic levels.
- *Forest health and vitality:* Management shall reduce potential for unwanted disturbances.
- *Productive functions of forest resources:* Management shall ensure the supply of primary forest products and secure sustainable production and harvesting without compromising management of future generations.
- *Socio-economic functions:* Acknowledge forests’ contributions to the economy as well as their traditional and cultural importance.

- *Legal, policy and institutional framework:* The importance of legal, policy and institutional arrangements for regulation, as well as focus on participatory decision making shall be acknowledged.

I defined sustainable regeneration from the number of recruits and the structure of the forest stand. The sustainability I refer to therefore mainly draws upon the FAOs 'forest health and vitality' because disturbance is thought to be reflected in these measures. This thesis focuses on natural regeneration, in the forest literature typically described by;

1. Structure (tree density and diameter size-class distribution; intact strata), *and*
2. Survivorship curves (seedling and sapling counts).

I touch upon FAO's 'productive functions of forest resources' and the 'legal, policy and institutional framework' in the qualitative analysis, although not quantified for statistical analysis.

Sustainable forest regeneration

By their importance for bringing about sustainable livelihoods, it has become of prime interest to manage forests and develop forest management strategies. Forests are for this purpose defined as sustainable when the following characteristics are met:

1. Survivorship diameter at breast height (DBH)-curves with a reversed J-shape, where:
   a) Individuals in DBH size class 5-15 > DBH size classes 15 – 25 > 25 – 35 etc.
2. Recruitment individuals where:
   a) Seedlings > Saplings
   b) Saplings > DBH class 5-15 cm
3. Intact strata, where the following layers are present and intact:
   a) Canopy
   b) Sub-canopy
   c) Shrub layer

Sustainability in terms of recruits (the combined term for seedlings and saplings) is defined as when the number of seedlings exceeds the number of saplings and when sapling numbers in the first size-classes outnumber the sum of trees.

Although lack of seedlings and saplings have been interpreted as an indicator of a population that suffers population decline (Condit et al. 1998), it is argued by Vetaas (2000b) that diameter distribution may be more effective than seedling counts to interpret long-term forest regeneration. Rubin et al. (2006) also agree that diameter distribution, if used carefully, can indicate whether the density of smaller trees in a stand can replace the current population of larger trees, i.e. it can be used to evaluate potential structural forest sustainability.

Sustainability of forests is therefore, partly, reflected through the structure of the forest stand. Structure can refer to the age, the size or the form of the forest. Age distribution might be a complicated and at times misleading predictor of regenerative behaviour, and it is therefore argued that size might better reflect reproduction and plant growth (Harper & White 1974). Structure of trees is therefore, in general, represented by species size-class distributions portrayed in frequency histograms, and described in regression curves.

The form of a size-class distribution is interpreted as reflecting the forest health and an indicator of forest viability (Rubin et al. 2006). A reversed J-shaped distribution descends steeply towards smaller size-classes. This form typically represents uneven-aged stands. It is interpreted as reflecting forests with sustainable growth (West et al. 1981). A reversed J-shaped distribution with constant percentage decrease in density between neighbouring diameter classes is referred to as negative exponential. Constant average growth and mortality rates similarly distributed over large areas reflect self-sustaining distributions (Rubin et al. 2006).

Non-sustainable forest regeneration

Diameter distributions can indicate forest-stand disturbances. Disturbance by humans can be of such character that it creates a response in the structure of the forest stand, e.g. by changing the forest basal area or the stem density. Disturbance may also be of the type that is not reflected in structural changes, e.g. by extraction of leaves or fruits (Ingram et al. 2005).

A unimodal/bell-shaped distribution reflects an even-aged forest stand (West et al. 1981): a forest with relatively few young and old trees, compared to intermediate-sized trees. The lack of trees at either end of the diameter size-class distribution has been attributed to disturbance and is expected to constrain regeneration (Saxena & Singh 1984; Måren & Vetaas 2007). A rotated sigmoid curve reflects a distribution with concave and convex curves, i.e. with decreases in small size-classes and increases in the larger size-classes. For this situation to be sustained, more small and large trees than middle-sized trees must die (Goff & West 1975). This curve is typically understood as describing unsustainable situations in which the species population abundance shifts (Leak 1964; Schmelz & Lindsey; Jackson & Faller 1973 in Rubin et al. 2006).

In addition to a hampered forest size-class distribution a non-sustainable forest is deficient in recruits. At least one of the stratification layers is lacking or is heavily disturbed. Consequently; forest degradation is here understood as a forest with a non-sustainable regeneration pattern, where disturbance factors and biomass outtake is greater than the natural regeneration, a definition in accordance with Grime (1979). Such a situation is expressed by a forest's failure to meet the characteristics (1-3) described for sustainability to be achieved. Forests that are non-sustainable and degrading have a bell-shaped DBH-curve which indicates that regeneration is hampered. In addition, recruits are lacking, shown by more saplings than seedlings. At least one stratification layer is missing or is heavily disturbed.

Consequently, forest degradation is here understood as a forest with a non-sustainable regeneration pattern, where the effects of disturbance in the form of biomass outtake are greater than the natural regeneration and growth.

Figure 1.1: Current forest disturbances observed in the field.

1.9.4 Forest management

Forest as a common-pool resource

"A common-pool resource is a natural or man-made resource from which it is difficult to exclude or limit users once the resource is provided, and one person's consumption of resource units makes those units unavailable to others" (Ostrom 1999 p 497). Common-pool resources are a major part of most discussions about resource management, often due to their high value and people's incentives to appropriate them. The "appropriation problem", i.e. people's incentives to appropriate more and more of a resource of high value that is not restricted by institutional constraints, may result in the 'free-rider' problem and end with overuse and resource-destruction (Ostrom 1999). Hardin (1968) and Ostrom (Ostrom et al. 1994; Ostrom 1999; 2005; Ostrom & Moran 2005; Ostrom & Nagendra 2006) agree up to this point; but part when it comes to the understanding of what possible effects user behaviour might have on common-pool resources. Ostrom (1999) criticizes the theoretical background in the field that to a large degree is based on Hardin's (1968) conceptions of common-pool resource management. She argues that implementation of uniform regulations on natural resources by the government is not empirically supported as an efficient management strategy. She summarizes field-evidence that demonstrates challenges with management implemented by governments and states her core argument: a well-evidenced belief in the power of individuals to gather in local groups, either by their own initiative or assisted by external authorities, to create arrangements and institutions to cope with common-pool resources in ways that are sustainable (Ostrom et al. 1994; Ostrom 1999). Ostrom uses CF as an example of an institutional arrangement where users have been successful in regulating commons (Ostrom & Nagendra 2006; Nagendra & Ostrom 2011).

Forest management in Nepal

Managing forests in Nepal, although they were being heavily exploited and the resource base was degrading, was not in focus until the 1950s (Mahat et al. 1986). The increased focus on common-pool resources and sustainability of forest ecosystems from this time has, however, facilitated the development of management systems. The forest legislation that emerged in the 1950s developed along a continuum (Figure 1.2) from total governmental control over forest resources manifested in 'The Private Forest Nationalization Act of 1957' to the involvement of local people in 'panchayats'/committees regulated by 'The First Amendment of the Forest Act' in 1977 (Mahat et al. 1986). Through the 'panchayats' people were involved in forests, and management developed in new ways: in addition to using forests, people were engaged in conserving and managing them too (Mahat et al. 1986; Gautam et al. 2004). 'Panchayat forests' are important because they are known to have "(…)sown the seeds of effective community forestry" (Mahat et al. 1986 p 227).

I study post-CF management (see Mahat et al. 1986 for pre-CF history), and my focus is directed towards the transition from government-controlled forest management, deemed as a failure with regard to protecting forests, and the contrasting response – local regulation by communities themselves (Figure 1.2).

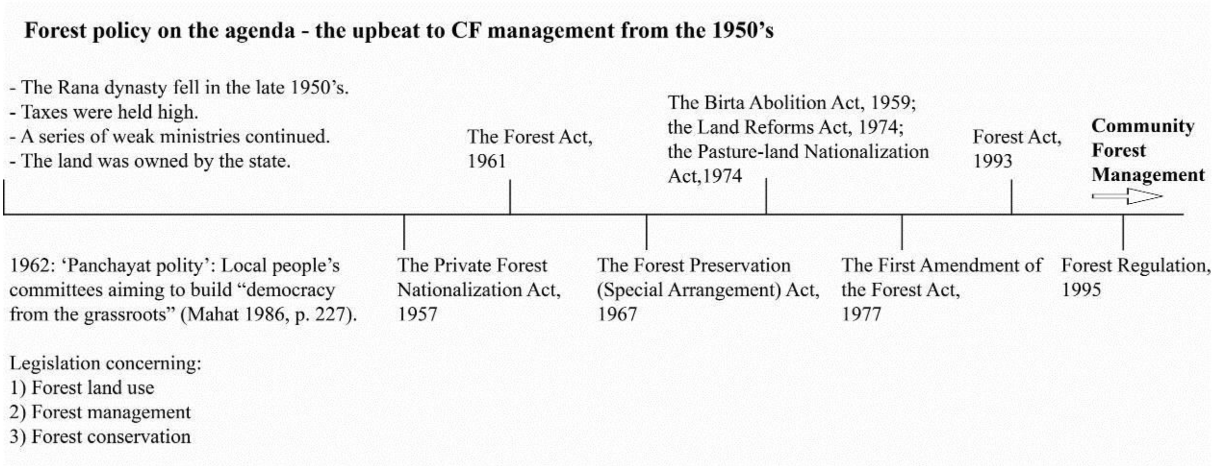


Figure 1.2: Forest legislation along a continuum towards the introduction of CF management. Information is based on Mahat et al. (1986).

Community Forestry as a management system

Community Forestry was introduced in Nepal in the late 1970s (Figure 1.2) (Mahat et al. 1986; Acharya 2002; Gautam et al. 2004) and have since extended to cover 33 % of the national forest area (FAO 2011), the majority (>70 %) in the Middle Hills (Department of Forest 2011). By 2011, the forest area under CF management was organized by *c* 17 500 CFUGs, representing about 40 % of all Nepalese households (Department of Forest 2011). This means that CF has expanded by *c* 3000 CFUGs, i.e. 5 % more involved households since 2006 (Blaikie & Springate-Baginski 2007).

CF management aimed to engage local communities in management and environmental conservation strategies (Brosius et al. 2005; Glasmeier & Farrigan 2005 in Pandit & Bevilacqua 2011), *and* to provide practices with respect to forest ownership, responsibility and management authority (Edmunds & Wollenberg 2003; Ribot et al. 2006 in Pandit & Bevilacqua 2011). Local management was initiated to halt and even reverse the continuing degradation and deforestation (Pandit & Bevilacqua 2011).

The present CF management is regulated by the Forest Act of 1993 and the Forest Regulation of 1995 (Ministry of Forests and Soil Conservation 1993) where forest is defined as “an area fully or partly covered by trees”. This legislation further states that a CF is a national forest that has been handed over to a user group for development, conservation and utilization that promotes the collective interest. Forests are handed over to local communities by the DFO which helps organise CFUGs and assist the preparation of a 5-year legal work plan. The work plan, approved by the DFO, is binding legislation that regulates how the CFUG shall develop, conserve and extract forest products, while at the same time maintain the environmental balance defined by the Forest Act of 1993 and the Forest Regulation of 1995 (Ministry of Forests and Soil Conservation 1993). The work plan further defines the forest status by the start of the five or ten-year period, the amount of forest products that can be extracted, the specific management activities to be undertaken, the rules for protection and the associated fines for rule-breaking (Chhetri et al. 2012).

Nepal is a forerunner of the adoption of CF management (Varughese & Ostrom 2001; Ostrom & Nagendra 2006). Many studies focus on the success of CF management in conserving forests (Thoms 2008), increasing collection rates (Adhikari et al. 2007) and generally improving the environmental conditions (Gautam et al. 2002; Dev et al. 2003; Tachibana & Adhikari 2009; Pandit & Bevilacqua 2011). Its success is however contested. For example, Gautam and Watanabe (2005) and Baral and Katzensteiner (2009) found that CFs which were strictly regulated were less diverse in tree species because species which were not seen as “useful” and valuable were removed from the forest. Impacts of CF management on socio-economic distribution patterns and rural livelihoods are also disputed. Thoms (2008) argues that CF management has a limited effect on improving rural livelihoods as the poorest households suffer the most from regulation of the use of forest-products. This is supported by Graner (1997) who critically argues that CF has even worked to the disadvantage of poor people. Another argument that CF management may lead to greater inequities between the elite and the marginalized human population is expressed by, for example, Gilmour (2003).

CHAPTER 2 STUDY AREA

2.1 Location

Nepal is a landlocked country in South Asia between the borders of China and India at 27-30° latitude and 80-88° longitude (Figure 2.1). The federal democratic republic of Nepal covers 141 181 km^2 (Central Intelligence Agency (CIA) 2013) in a rectangular shape with a short edge of 870 km and an east-west stretch of more than 3000 km (Singh & Singh 1987). Nepal is situated in the southern part of the Himalayan range which encompasses some of the world's tallest mountains.

The Himalaya are generally divided into three main mountain ranges that run south-east to north-west in Nepal (Hagen 1969; Singh & Singh 1987). These ranges are intersected by deep transverse valleys reaching from the south to the north of the country, framing the land in between (Figure 2.2; Figure 2.3). Starting in the south from the alluvial plains of the Ganges in the lowland Terai, the land rises towards the first mountain range, the Siwaliks. The Siwaliks are 10-50 km wide with elevations between 500-1200 masl (Singh & Singh 1987). The Siwaliks are followed by the outer Himalaya from around 2500 masl, a chain that stretches from northwest to southeast (Singh & Singh 1987), referred to by Hagen (1969) as the Mahabharat Lekh, and characterized by folds and thrusts that form steep slopes and rough terrain intersected by deep and narrow gorges. Towards the northern part of the country the Great Himalaya, permanently snow-clad peaks rising to elevations above 8000 masl, dominate the landscape (Singh & Singh 1987). The much used terms “Mid Hills/Middle Hills” or “lesser Himalaya” loosely refer to the area between the Siwaliks and the Great Himalaya (e.g. Singh & Singh 1987; Singh & Singh 1992; Paudyal et al. 2011).

This specific study is located in a watershed in the Middle Hills of central Nepal (Figure 2.1;Figure 2.2;Figure 2.3). Ludikhola watershed is in the south of the Gorkha district close to the district headquarters, the village with the same name. It comprises an area of 5750 ha located between 84° 33’ 23’’ to 84° 40’ 41’’ east and 27° 55’ 02’’ to 27° 59’ 43’’ north. The watershed stretches vertically from 318-1714 masl (International Centre for Integrated Mountain Development ICIMOD; Asia Network for Sustainable Agriculture and Bioresources ANSAB; The Federation of Community Forestry Users Nepal FECOFUN 2010).

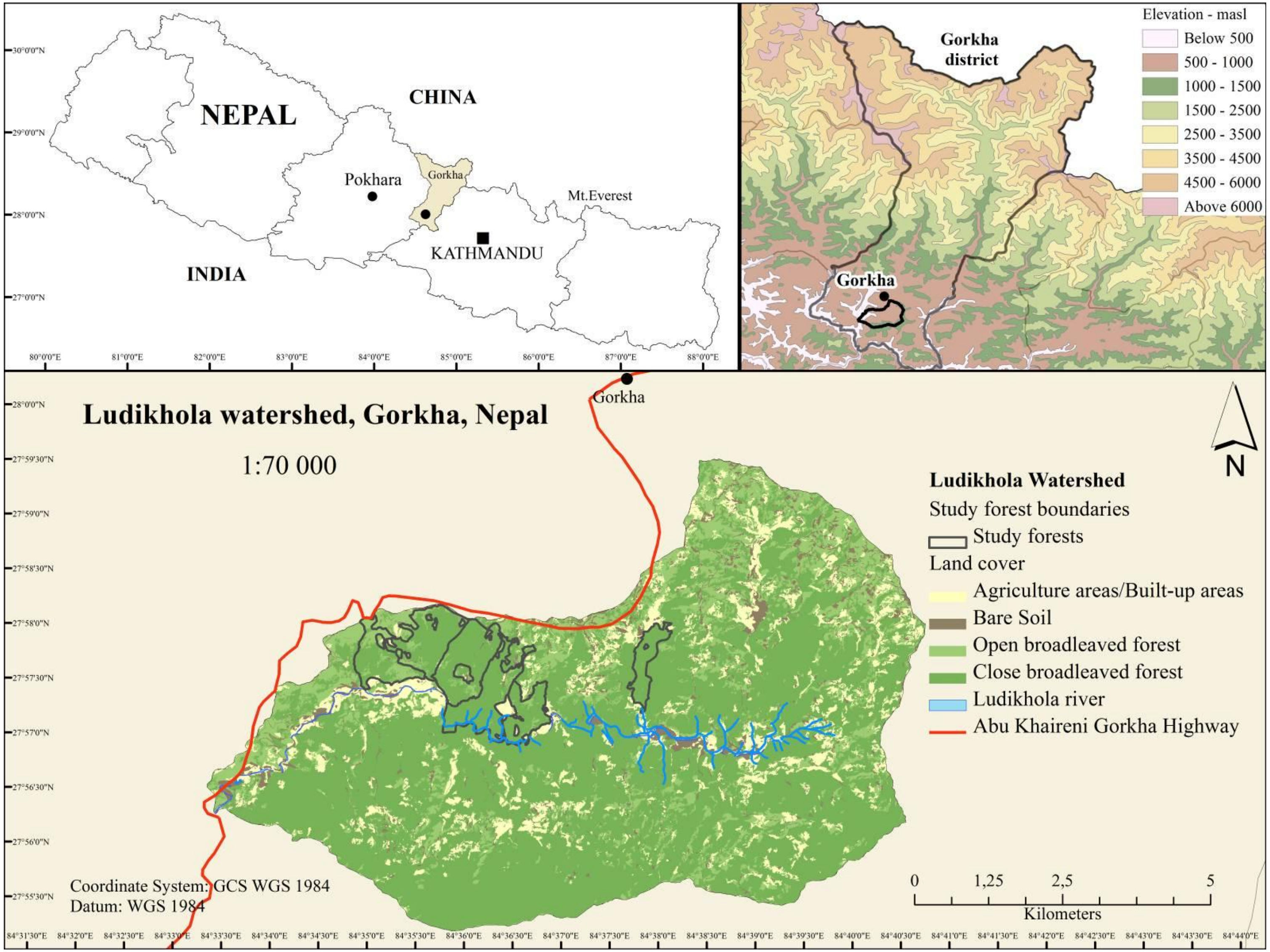


Figure 2.1: Map showing the location of the study area, Ludikhola watershed in Gorkha district, central Nepal. Map layers obtained from ICIMOD (2010).

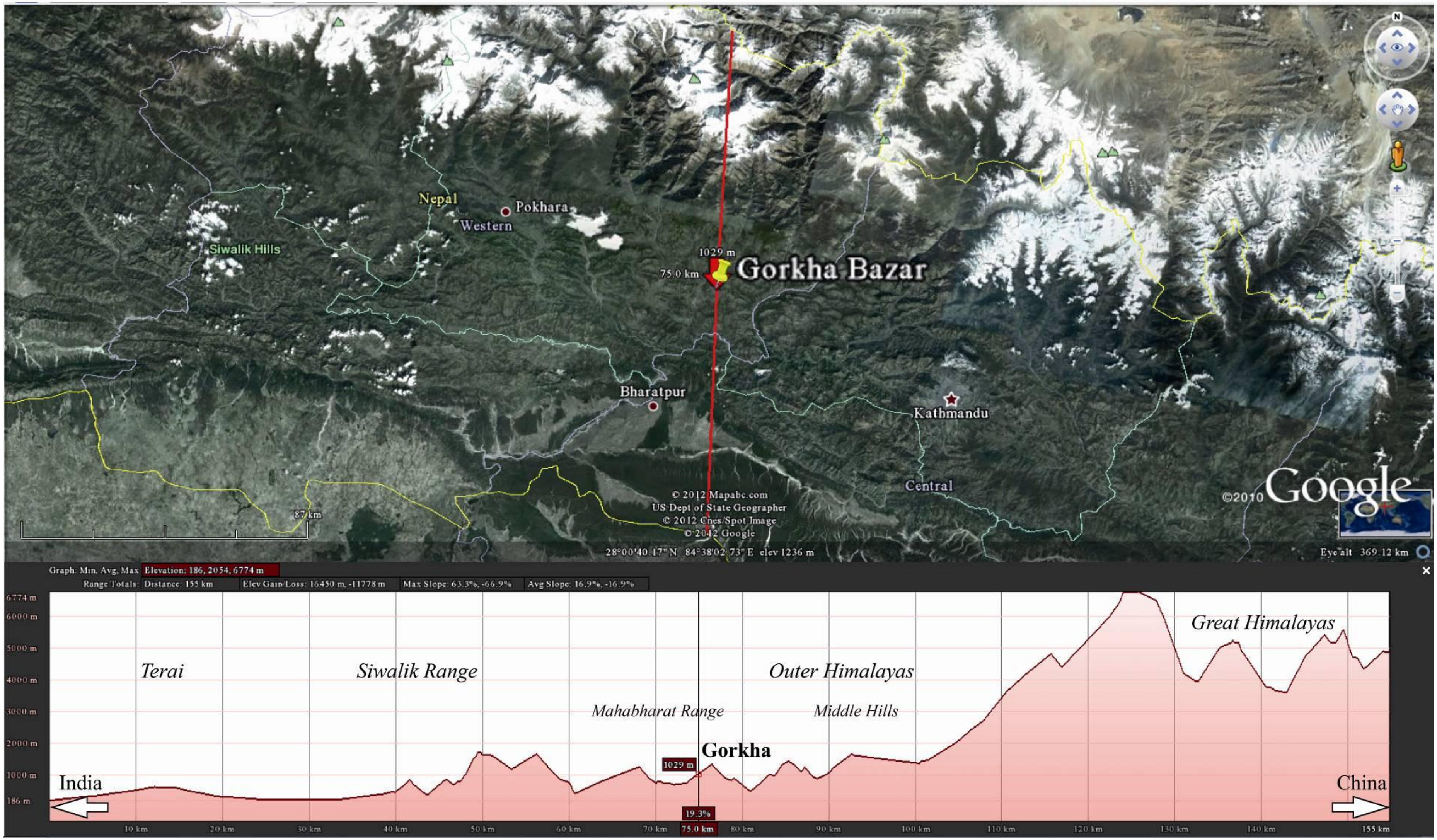


Figure 2.2: South-north elevation profile drawn through Gorkha Bazar, Nepal. Satellite picture from Google Earth (2010). Profile modified with names by the author.

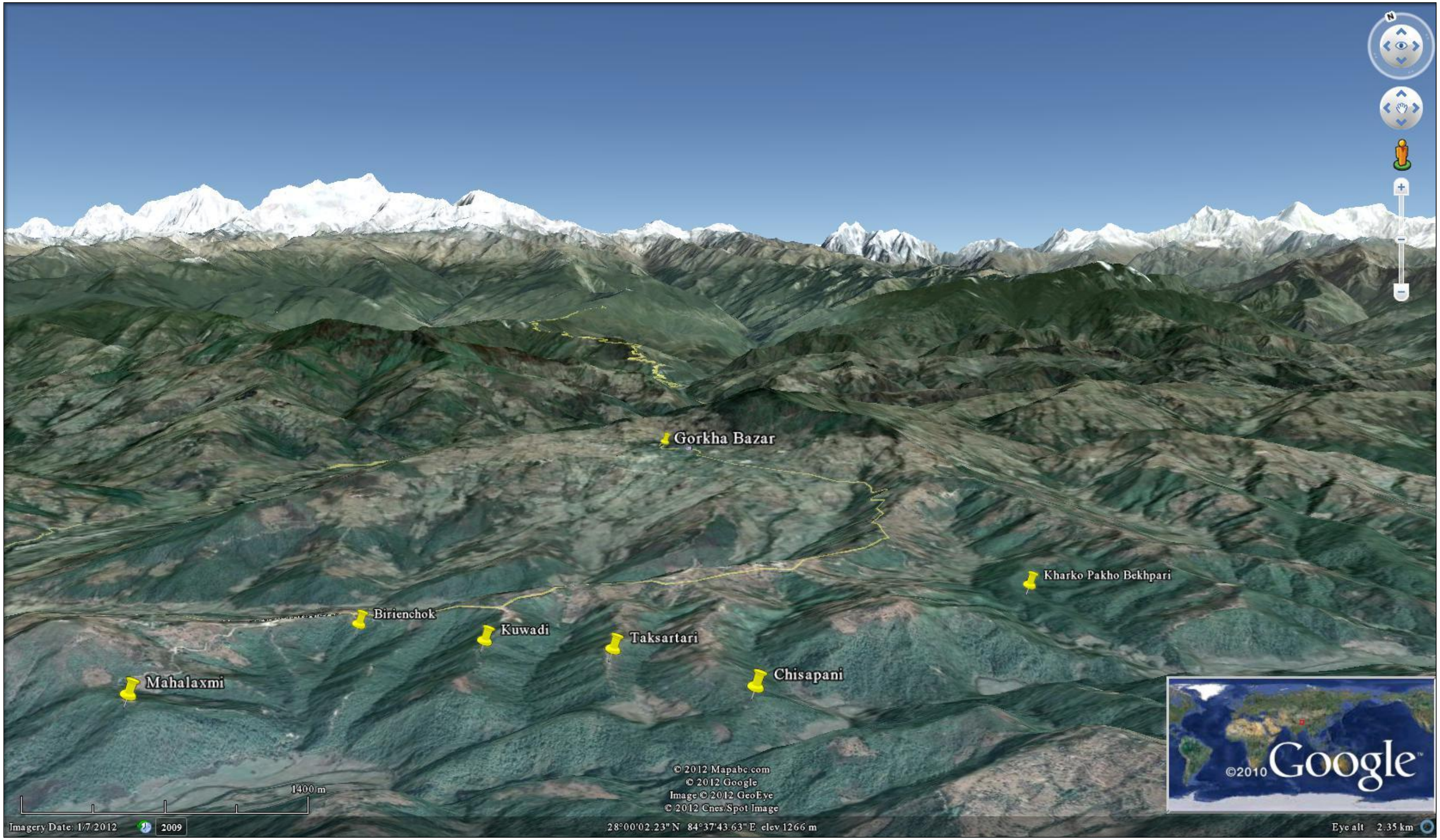


Figure 2.3: The dramatic mountain landscape of Nepal. The yellow pin-points represent Gorkha Bazaar to the north and the six forests farther south. Abu Khaireni Gorkha highway is drawn in yellow. The satellite picture is modified from Google Earth (2010).

2.2 Geomorphology and Geology

The geological structure of Nepal has played a major role in forming the Nepalese landscape (Hagen 1969). The Himalayan ranges reflect the physical movement of the Indian plate and the following massive mountain folding and uplifting that occurred when it rammed into the Eurasian plate 40 million years ago. The crumbling and compression of the Indian continent into the Eurasian plate has continued since (Fossen 2008), and created what is, by Hagen (1969), described as a geological structure of nappes thrust over large distances to where they are present today. The Himalaya forms a dynamic geomorphic system where deformation by on going plate motions, mass transfer and mantle earthquakes are characteristic features (Nábělek et al. 2009).

The Middle Hills, covering elevations from 600 – 2000 masl, is separated to the south by the edge of the Mahabharat range. The soil, dependent on the subsoil rocks from which it has been weathered and eroded is generally fertile in the Middle Hills (Hagen 1969). Paudel, Pokharel and Prasad’s (2011) studies of petrography in Gorkha district outline that phyllites of various composition dominate the Kunccha Formation, which forms a nappe in the study area. However, as argued by Polunin and Stainton (1984), altitude, aspect and rainfall are more important factors than the chemical composition of the bedrock and the soil in explaining the present vegetation types in areas influenced by the monsoon.

2.3 Climate

Nepal has a monsoonal rainfall pattern characterized by higher precipitation during summer months than during the rest of the year. The amount of annual rainfall declines from east to west. Two-thirds to three-quarters of the annual rainfall in the east and central Himalayan region is received during the rainy season, i.e. from mid-June to September. The distinct pattern characterized by heavy monsoonal summer rain decreases towards the western region where winter rain is more prominent (Singh & Singh 1987).

Temperature varies greatly throughout Nepal resulting from the extensive elevation differences (Singh & Singh 1992). The relationship between elevation and temperature is expressed by the national lapse rate that predicts a temperature decrease by 0.51°C per each 100 m increase in elevation (Anon. 1998; Dobremez 1976 in Vetaas 2000a). Nepal’s exceptional elevation range is thereby the prime determinant of the climate and the divisions in climate zones. Temperature trends show some spatial variation throughout the country. However, the general trend report that the mean annual temperature between 1976-2005 has increased in almost the entire country (Suresh et al. 2009).

Mean annual rainfall over the last 40 years is *c* 1700 mm, based on data from Gorkha climate station at 1097 masl (Department of Hydrology and Meteorology 2012), covering the period from 1970 to 2010. The average annual minimum temperature for the same period was 15° C and the maximum close to 26° C (Figure 2.4).

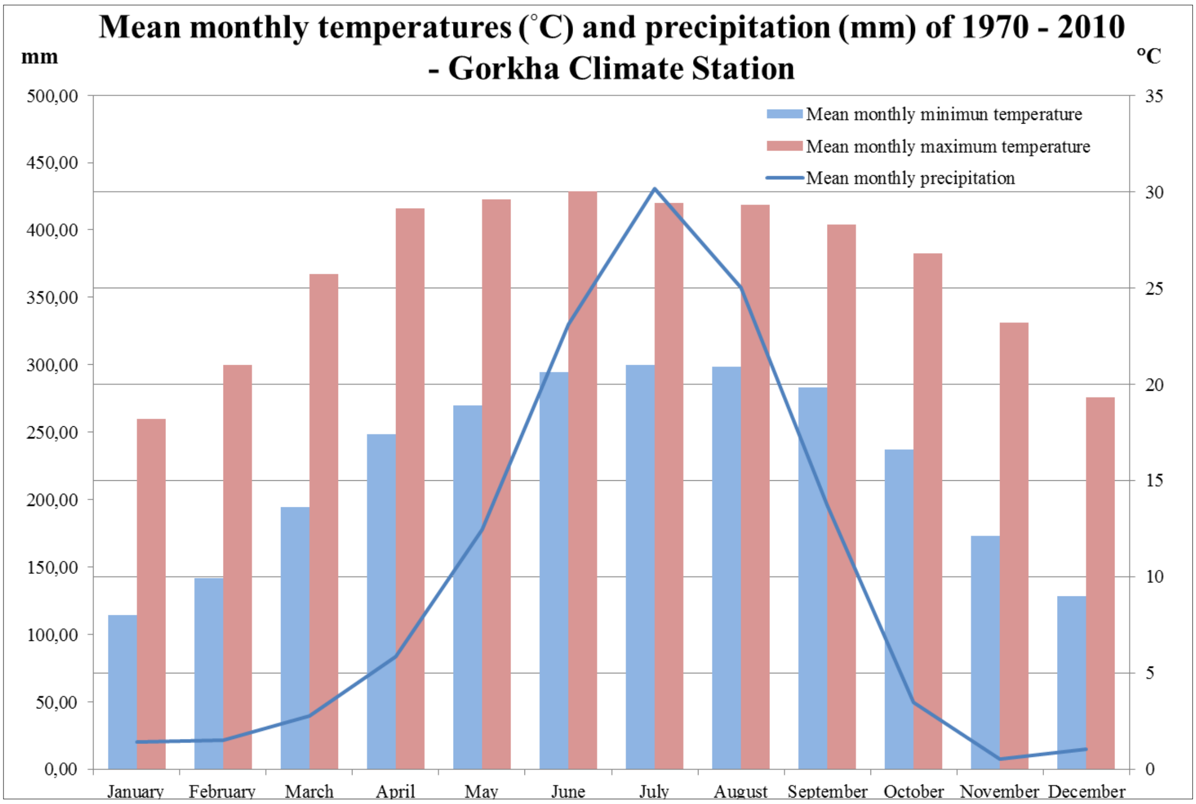


Figure 2.4: Gorkha Climate Station – Mean monthly (minimum and maximum) temperatures (°C) and mean monthly precipitation (mm). Averages based on data from 1970 to 2010. Data obtained from Department of Hydrology and Meteorology (2012).

Although Lamichane and Awasthi (2009) report that annual rainfall has increased in Ludikhola watershed from 1978 until 2006, data from Gorkha climate station indicate the opposite (Figure 2.5).

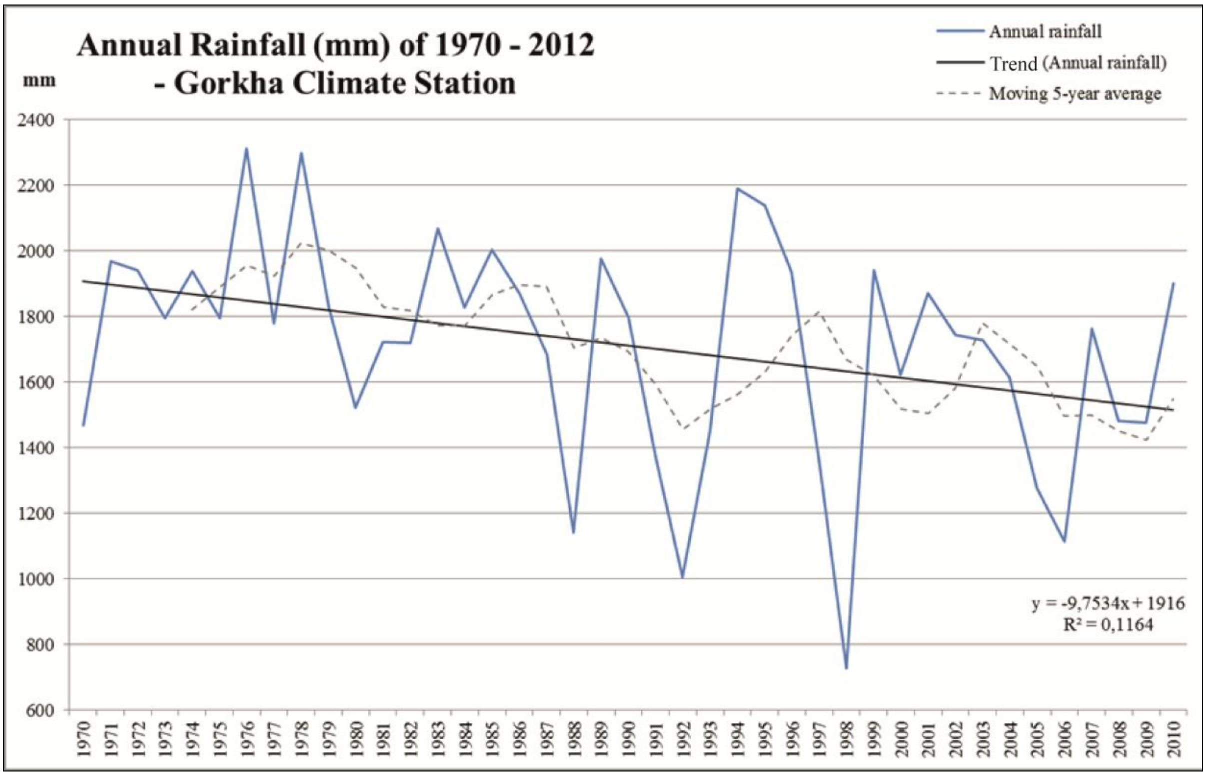


Figure 2.5: Gorkha Climate Station. Annual rainfall (mm) and moving 5-year average of 1970-2010. Data obtained from Department of Hydrology and Meteorology (2012). Note that this graph corresponds to data from the area covered by Gorkha Climate Station, an area greater than that of the specific study of Lamichane and Awasthi (2009).

According to preliminary studies Ludikhola watershed receives an average annual rainfall of *c* 2000 mm. The mean annual temperature is 23.1°C (ICIMOD et al. 2010). These findings are specific for Ludikhola watershed, while data gathered from the Gorkha Climate Station covers a greater area.

2.4 Vegetation

Singh and Singh (1987) divide the Himalaya in three major botanical regions. The western region is the area west of 77° E, characterized by species with Euro-Mediterranean affinities. Conifers are well distributed, whereas epiphytes are rare. *Shorea* originally belongs to the western region, reaching no farther than to 85° E. The eastern region conforms to the area beyond 84° E. Glaciation during the Pleistocene had little impact on this region, and subsequently a stable environment with species with Chinese and Malaysian affinities had time to develop. In lower areas of this region forests are described as evergreen broadleaved sub-tropical rain forest. Tree ferns and epiphytes are prominent, whereas conifers mix with typical rain forest vegetation (Singh & Singh 1987). The central region is situated in between these two regions, extending from 77° to 84° E. Its position wedged between the western and eastern region explains its mixture of Euro-Mediterranean and Chinese-Malaysian floristic affinities (Singh & Singh 1987).

Forest vegetation in the Himalaya is by Shresta (1989) and Singh and Singh (1987) divided and defined into 11 different formation types. For this study I use Singh and Singh's (1987) classification to explain the forest type in the study area. This classification emphasizes leaf characteristics and temperature/rainfall (as a factor of elevation) when defining the forest types.

2.4.1 Forest type in the study area

Ludikhola watershed, located at 84° E longitude is on the border between the central and the eastern botanical region. Based on Singh and Singh's (1987) regional botanical division we expect this location to be characterized by a mixture of European-Mediterranean and Chinese-Malaysian floristic affinities.

Singh and Singh (1987) define forests occurring mainly in central and eastern regions, where mean annual temperatures are between 21° to 26° C, and where the seasonally distributed annual rainfall fluctuates between 1000 and 1400 mm for "Submontane Seasonal Broadleaf Forest". This forest type is characterized by a tree and shrub layer that consists mainly of evergreen, deciduous species. *Shorea* is the dominant species. It accounts for 60-90 % of the top canopy. Other species commonly found within this forest type are *Schima, Stereospermum personatum* and *Caschela microcarpa.* These forests extend to elevations at about 1000 masl and occasionally higher. They cover a variety of rock and soil types. The canopy is usually dense, and consequently the sub-canopy is less developed. Seasonality is distinct, and leaf drop impacts on trees during summer. Trees are however never bare as leafing is multiple and extended (Singh & Singh 1987).

The studied forests in Ludikhola watershed conform to Singh and Singh's (1987) "Submontane Seasonal Broadleaf Forest". Several of the characteristics defined by Singh and Singh (1987), e.g. elevation range, temperature and species dominates, apply to the studied forests:

- The watershed is located on the border between the east and the central region (Singh & Singh 1987).
- The species that ranks first is *Shorea*. One of its associates is *Schima* (ICIMOD et al. 2010).
- Plot elevation range varies from about 600 to 800 masl, i.e. less than the maximum elevation range given for this forest type (ICIMOD et al. 2010).
- The mean annual and seasonal distributed precipitation is between *c* 1700-2000 mm (Calculations based on data from Gorkha climate station,1970-2010, obtained from ICIMOD et al. 2010; Department of Hydrology and Meteorology 2012).
- Mean annual minumun temperature is 15° C and maximun is 26° C (Department of Hydrology and Meteorology 2012). The mean annual temperature is 23.1 ° C (ICIMOD et al. 2010).

Figure 2.6: The view from Mahalaxmi community forest in Ludikhola watershed, facing in the direction of Manakamana, a sacred landmark. The characteristic landscape, consisting of a main east-west trending ridge-structure with minor north-south ridges that terminate in the valley-bottom within, is easily seen.

Target species

This study focused on natural regeneration of two tree species, namely *Shorea* and *Schima*. These species were chosen for this project for severeal reasons, among them because preliminary information was available for *Shorea*, and its associate *Schima*, which dominate Ludikhola watershed (ICIMOD et al. 2010).

Ohsawa (1986) made a comparison of the different vegetation zonation schemes of eastern Nepal. This summarizes which species are commonly found in each vegetation zones. All the various schemes (Kawakita 1956; Banerji 1965; Numata 1966; Bhatt 1970; Ohsawa et al. 1975; Dobremez & Shakya 1975 in Ohsawa et al. 1986) place *Shorea* and *Schima* forest at the lower end of the elevation range, in the tropical, sub-tropical or warm-temperate zone. It is important to note that *Shorea* is the dominant species within its occupancy range, and that *Schima* is one of its habitual associates when elevation slightly increases. Figure 2.7 shows the species elevation range and its assumed abundance. From this we can expect *Shorea* to be the dominant species within the limited sampling range. *Schima* is expected to increase in number at higher elevations.

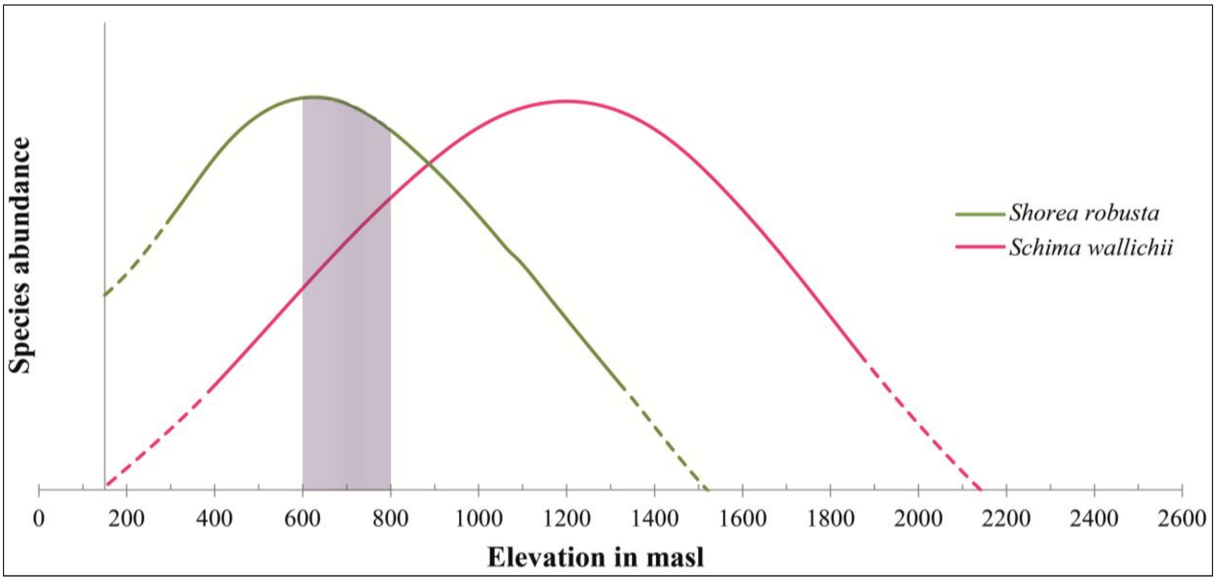


Figure 2.7: Model of the assumed abundance of *Shorea robusta* and *Schima wallichii* along the elevation gradient. The grey field indicates elevation range of sampling. Species elevation range is adopted from Ministry of Forests and Soil Conservation (2002). Dotted l line indicates uncertainty regarding species minimum and maximum range. Model in accordance with Whittaker's (1967) gradient analysis of vegetation.

Based on distribution mapping by ICIMOD (2010) "Hill-Sal" forest and the Schima-Castanopsis forest cover the following extent in Nepal (Figure 2.8).

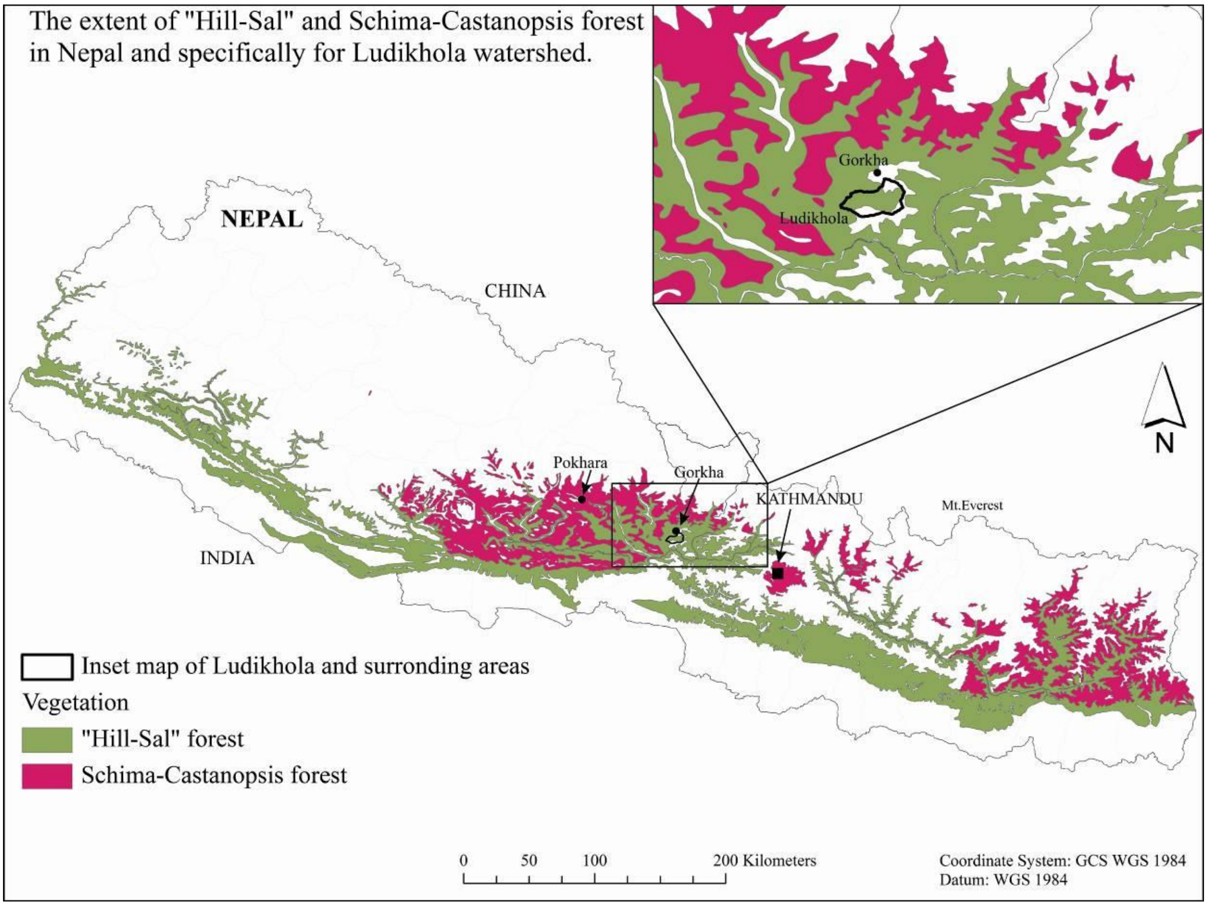


Figure 2.8: The extent of "Hill-Sal" and Schima-Castanopsis forest in Nepal. The inset map shows Ludikhola watershed and surrounding areas. The categorization shows no distribution of Schima-Castanopsis in Ludikhola watershed although both species were present. Map layers obtained from ICIMOD (2010).

Shorea robusta Gaertn.f. (Sal)

Shorea robusta Gaertn.f., locally known as 'Sal', belongs to the *Dipterocarpaceae* family characteristic of the tropical zone. It is a deciduous, broadleaved tree, distributed especially in outer tropical/sub-tropical valleys across the sub-Himalayan tract to Assam (Storrs & Storrs 1990). *Shorea* is categorized in two types (Figure 2.9). "Hill Sal" refers to *Shorea* forest in upper tropical, tropical, sub-tropical and northern tropical dry deciduous forests, while "lower Bhabar Sal" belongs to the tropical forests in the lowland Terai/Bhabar (Sapkota 2009). Vertically *Shorea* is distributed from the lowland Terai to about 1000-1500 masl (Figure 2.7). Storrs and Storrs (1990) refer to an elevational range from the Terai to 1200 masl, whereas Orwa et al. (2009b) and Polunin and Stainton (1984) refer to a stretch in elevation from around 100 to 1500 masl.

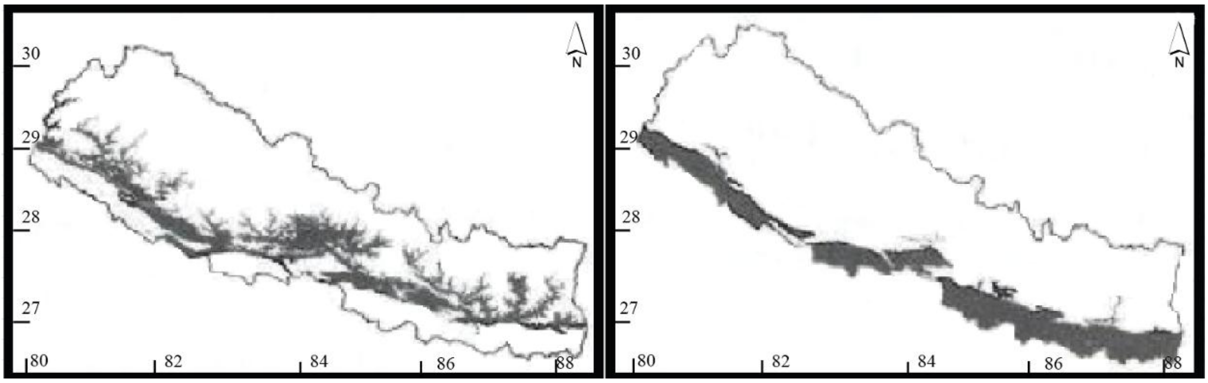


Figure 2.9: The two categorizations of *Shorea robusta* and their distribution in Nepal. Left: "Hill Sal", the one that is distributed in Ludikhola. Right: Lower Bhabar Sal. Illustration adopted and modified from Anon 2002 in Sapkota (2009).

According to Orwa et al. (2009b) *Shorea*, a light-demanding self-incompatible species, grows best on well-drained moist and sandy loam where the Mean Annual Temperature (MAT) are between 22 and 27°C (min 1-7°C; max 34-47°C) and mean annual rainfall is between 1000-3000 mm (max 6600 mm). *Shorea'*s normal height range is between 18 and 32 m, but they can, in extraordinary and favourable conditions reach 50 m and obtain a DBH of 5 m. In favourable conditions the plants grow quickly and they can reach 6 m in only six years (Orwa et al. 2009b). The trunk, covered by smooth grey-brown bark on young trees and darker and rougher bark on older trees, is straight and cylindrical, often with epicormic branches. The spherical tree crown (Orwa et al. 2009b), has a "leathery" and shining canopy of oval to oblong leaves that stretch 10 – 30 cm in length. *Shorea* is seldom leafless (Polunin & Stainton 1984), although its leaf drop peaks between mid-February and mid-May (Misra 1969; Pokhriyal et al. 1987 in Troup 1975b; Gautam & Devoe 2006). Between March and April, hanging bunches of pale, yellow flowers can be seen. The fruit is oval and covered by a white bloom (Storrs & Storrs 1990).

Shorea regenerates from seed, or it sprouts from root suckers and after coppicing (Gautam & Devoe 2006). Trees from seed origin and coppicing produce fertile seeds from an early age. *Shorea* is a moderate seed producer that on average produces seeds every two years. The seeds, dispersed by wind up to 90 m from the parent tree, ripen from the 3rd week of May until the beginning of July. The monsoon is critical for germination and seed drop is concentrated at its start. Seeds are highly fertile immediately after they have been dispersed, but the viability declines fast and they are destroyed within 3 weeks if rain is not received (Troup 1975b). *Shorea* is light-demanding. Overhead light from openings in the canopy promotes regeneration and is therefore especially important for germination and seedling establishment. If soil moisture is limited, partly shaded areas might provide better growth conditions (Troup 1975b). *Shorea* typically regenerates *en masse* where growth conditions (light, soil type, moisture, drainage) are favourable. This tends to create forest stands that are relatively even-aged (Troup 1975b). *Shorea*'s strong tolerance of coppicing, its immediate germination if rain is received, its heavy leaf fall that often suppresses seedlings of other species and its longevity makes *Shorea* the most widespread species within its habitat (Champion 1923 in Troup 1975b).

Shorea is described by Rautinainen and Suoheimo (1998) as the most important tree species in Nepal. Polunin and Stainton (1984) refer to it as the dominant and most important hardwood tree of much of the sub-Himalayan Hills. The importance of *Shorea* is tightly connected to its multiple uses. In addition to being one of the main timber trees, characterized by highly durable and resistant wood used for construction purposes, it is used as firewood and in temple carvings. The leaves are used as fodder for animals, and also to make "plates" for cooking and religious purposes. The resin is used for incense, and oil for various uses can be extracted from the seeds/fruits (Polunin & Stainton 1984; Shrestha 1989; Storrs & Storrs 1990).

The present status of *Shorea* forests results from actions and interactions of environmental and biotic factors (Gautam & Devoe 2006). This includes anthropogenic factors such as fire, lopping, litter collection, and grazing. The pressure on *Shorea* forests increased significantly in the 1950s. This was mainly the result of clearing forests to create agricultural land at the Terai, but partly also the result of *Shorea*'s various uses. By 1993 the distribution was estimated to decrease at a rate of 1.3 % annually (Forestry Sector Institutional Strengthening Programme 1993 in Rautinainen & Suoheimo 1998). Despite the extensive degradation in *Shorea* forests, Rautinainen and Suoheimo (1998) report that the species regeneration potential is good if management strategies are changed.

Figure 2.10: *Shorea robusta*. Left: intensively lopped individuals on a forest slope. Upper right: the dark brown bark with the characteristic longitudinal fissures. Lower right: fresh leaves are good fodder and intensively lopped.

Schima wallichii (DC.) Korth. (Chilaune)

Schima wallichii (DC.) Korth., locally known as 'Chilaune', is an evergreen sub-species of the Theaceae family indigenous to the sub-Himalayan region. Different zonations, based on climate as a factor of elevation, ranging from tropical, sub-tropical, warm-temperate to temperate (Ohsawa et al. 1986) are found in the literature for *Schima*. According to Polunin and Stainton (1984), as well as data by the Ministry of Forests and Soil Conservation (2002), *Schima* is distributed at elevations ranging from 200-2000 masl and 200 – 2100 masl, respectively, whereas Sheresta (1989) and Storrs and Storrs (1990) refer to an elevation range of 700-2000 masl and 600 – 1800 masl, respectively (Figure 2.7). At lower elevations *Schima* is a sub-dominant species with *Shorea*, while it at higher elevations, especially in areas east of Kali Gandaki, it is frequently associated with *Castanopsis indica* (Figure 2.8). At this elevation it is often the dominant species within its elevation range (Storrs & Storrs 1990).

Schima has a straight cylindrical trunk and grey bark with vertical fissures (Storrs & Storrs 1990). It can reach a height of 47 m and a DBH of 2.5 m at favourable locations. It demands MAT of 0 –

5°C (min) and 37 – 45°C (max) and a mean annual rainfall favourably between 1400 – 5000 mm. Trees of *Schima* grow on a wide range of soils and they tolerate various climates (Orwa et al. 2009a). The crown is round and dense, consisting of leaves that are "leathery", elliptic-oblong, 16 cm long and 6 cm wide. During May to June, small clusters of white flowers bloom. In late summer, the fruit, a brown, woody capsule, ripens (Storrs & Storrs 1990). *Schima* seeds, dispersed by wind and by parrots who feed on ripe capsules, are dependent on rains to germinate. *Schima* is characterised as a moderate light demander, but despite that seedlings can spring up in shade, development to sapling and tree level requires light (Troup 1975a; Orwa et al. 2009a). Good seed years are common and natural reproduction is good within its habitat (Troup 1975a), although some argue that *Schima* suffers from inefficient reproduction due to high seed sterility, poor seed germination and high seed mortality (Boijh 1981; Chauhau et al. 1996; Goswami et al. 2003 in Goswami 2012).

Timber of *Schima* is durable and strong, categorized as medium/heavy hardwood useful for construction purposes. It also produces good firewood. The leaves are lopped and serve as fodder (Orwa et al. 2009a), although not as intensively as for some other species (Storrs & Storrs 1990).

Figure 2.11: *Schima wallichii*. Left: an undisturbed individual depicting its natural spherical crown. Upper right: fresh leaves sprouting during spring. Lower right: the white fragrant flowers of *Schima wallichii*. A woody ripe seed capsule can be seen in the background.

2.5 Traditional subsistence agriculture in transition

Subsistence agriculture, i.e. *local* production by *local* labour for *local* consumption, characterizes the indigenous rural economy of Nepal (Schroeder 1985; Mahat et al. 1986).
In this society, access to land is of prime importance, while trade and commercial activities have less significance for securing people's livelihoods (Mahat et al. 1986). Agricultural inputs are few and the world market has only limited influence on the subsistence economy of Nepal (Schroeder 1985).

Subsistence agriculture, present at elevations stretching from the Terai to about 4000 masl (5200 masl during monsoon) is limited by water availability and temperature. Water availability is determined by climate, and seasonality is distinct (Schroeder 1985). Temperature is directly related to elevation and therefore limits which crops can be grown. The potential for agriculture in general decreases with an increase in elevation (Guillet 1981 in Schroeder 1985). For subsistence agricultural systems to sustain the livelihoods of the people, they depend on available biomass (Moench & Bandyopadhyay 1986). The relationship between agriculture, animal husbandry and forest products are dependent on available biomass. This is described by Moench and Bandyopadhyay (1986) as a 'biomass flow system' in which available resources of biomass flow between agriculture and husbandry. The described system refers to the village Munglori, but the described fodder, fuel and migration cycles, are general and to some degree parallel for similar subsistence communities.

The 'fodder cycle' is the basis for the energy and nutrient flow (Moench & Bandyopadhyay 1986). Fodder is a term for grasses and leaves of various types that are consumed by animals, either through grazing and browsing, or collected and brought home to stall-fed animals. Grasses and leaves are returned to the land as dung, which fertilizes the soil and enhances production of biomass (Aase & Vetaas 2007). Sustainability is secured as long as the flow of energy and nutrients that are turned into biomass exceed demand. If much energy and nutrients are lost to the society's resource base and the provision of fuel and fodder is insufficient, the system degrades. The 'fuel-cycle' refers to cutting biomass (twigs, branches and whole trees) to obtain fuel, while the 'migration cycle' describes the flow of people from one area to another (Moench & Bandyopadhyay 1986).

Subsistence agriculture and small-scale farming are still prominent in large parts of Nepal, although external influences drive the society in direction of the world market. This is especially evident where tourism is widespread. Bjønness (1983) describes this as a 'transitional agricultural system' characterized by intensified modern systems where dependence on labour is high, connection to the world for import of food and cash income important and where migration plays a central role.

2.5.1 Subsistence agriculture mixed with market access in CFs and Gorkha

Gorkha municipality has a total population of 33 865 people comprising *c* 8800 households each with around 4 people. The municipality comprises an area of around 60 km^2 and the population density is relatively high at 562 persons per km^2 compared to the national average of 180 (CBS 2012). Gorkha town is the headquarters of Gorkha district. It comprises the urban facilities expected of such a place: a bazaar (Nepali market) and medicinal and administrative services. The road to Gorkha from connecting areas improved with the construction of the Abu Khaireni Gorkha highway, finished in 1982 (Fox 1993). Tourism is restricted to Nepalese people who flock to Gorkha because of its importance as the centre from which Nepal was unified by king Prithivi Narayan Shah in the mid-18th century, the origin of the Gurkha soldiers as well as for the religious importance of a landmark temple.

The villages associated with the forests where I worked are closely connected to Gorkha town by the highway. It takes less than 30 minutes to drive and no more than two hours to walk from the most distant forest to Gorkha. The villages are located on top of the ridge which the road also follows. The road is easily reached by most households and transport to the city centre is affordable for most people. The proximity to Gorkha enables the purchase of goods in the bazaar in addition to the reliance on subsistence agriculture. Although villagers can easily access Gorkha and to some degree take part in the monetary economy by purchasing goods at the market, they still rely on forest products for sustaining their livelihoods (Figure 4.17). Forest product collection is regulated by the rules and practises of the CFUGs. Fodder collection is widespread and most households collect leaves and twigs to feed buffaloes every day. Goats are taken to surrounding areas to graze. Dung from stall-fed buffaloes is used as manure in small-scale local farming or to produce gas for the improved cooking stoves seen in a few households. Dry firewood is collected year round, but cutting of live trees to obtain timber and firewood is regulated by the CFUG. The 'biomass flow' (Moench & Bandyopadhyay 1986), and especially the 'fodder-cycle' is applicable to the studied villages in Gorkha (Figure 2.12).

Figure 2.12: The simplified 'fodder cycle' of CF villages in Ludikhola. The ‘fodder cycle’ is probably the most important component of the energy-nutrient flow in subsistence agriculture systems. The cycle structure is adopted from Moench and Bandyopadhyay (1986).

CHAPTER 3 METHODS

This chapter describes the methods used for analyses of forest regeneration under CF management. Quantitative methods typically address a phenomenon's extent, size and volume, while qualitative research aims to reach a deeper understanding of the phenomenon's nature and essence. Where qualitative methods tend to focus on interactions between people *and* analysis concerning roles, relationships and communication, quantitative methods compare groups and individuals in entities that are measureable and distinguished from one another (Aase & Fossåskaret 2007). Quantitative and qualitative methods are therefore by many researchers seen as complementary in obtaining knowledge. They provide their unique dimensions that together unite these methodological traditions (Aase & Fossåskaret 2007).

This thesis reflects my view, that if I am to obtain the most comprehensive understanding of forest regeneration and management in Ludikhola, I must produce a geographical synthesis that makes use of quantitative methods to outline the patterns and the extent of regeneration *and* qualitative methods that can explain these outlined patterns. Triangulation means "using multiple data sources and/or research methods to strengthen your results" (Nicholas et al. 2010 p 536). My prior aim is to make a synthesis on this basis. To answer my research questions and to test the hypothesis I will primarily focus my research quantitatively. However, qualitative data has an important role in contextualising the study and in understanding the degree to which management really matters for explaining the patterns of regeneration. I will explain the field, numerical and qualitative methods used for this study before I proceed to the results.

3.1 Pre-field methods

The main focus of the research is to elucidate where the forests are sustainable with respect to use and regeneration of the canopy dominates. The sampling aims to record in a relatively unbiased approach the ability of the forest to produce seedlings and how many of them have survived to become saplings and trees.

3.1.1 Locating the study area

Ludikhola watershed (Figure 2.1) in the south of the Gorkha district is one of the case studies in a project led by ANSAB, ICIMOD and FECOFUN (2010), funded by The Norwegian Agency for Development Cooperation (NORAD). This is a pilot $REDD^{+}$-project (Reduced Emission from reduced Deforestation and Degradation in Developing Countries) called “Design and setting up of a governance and payment system for Nepal’s Community Forest Management under REDD”. This implied that useful preliminary information was available. This includes specifications of forest types, total CF area and number of households with user rights to the CFs.

The field area was chosen because of its suitability for this type of study. Forests in Ludikhola were appropriate as they met the inclusion criterion that all forests should have a presence of mature trees, i.e. trees that have survived the progressive degradation period before hand-over of forests to community management about 20 years ago. This criterion ensured that the forests can be understood in the historical context applied to explain the regenerative pattern of the studied forests in Ludikhola. This is based on the assumption that the study area must have been under CF management over some time, as this is expected to ensure that the present degree of use is represented through the forest regeneration.

A pre-visit to the watershed was conducted by my supervisor professor Ole Reidar Vetaas and my field supervisor Lila Nath Sharma in 2011. The research team decided, along with ICIMOD, to conduct research in Birienchok, Kuwadi, Taksartari, Chisapani, Shikhar and Kharko Pakho Bekhpari (KP Bekhpari) as they conformed to the criteria. These specific CFs were, in addition to the main criteria, chosen for their relative proximity to each other, their accessibility to the road, their topography and the variation in forest user-density, *cf*. H_1 and distance to Gorkha, *cf*. H_2.

During field work in 2012 it was decided that Shikhar had to be excluded from the study area. This was due to the inability to make 15 plots within the working elevation as slopes were exceeding 40°. Because of the potential danger and difficulties related with work in such steep areas Shikhar was excluded. In order to maintain the predefined number of comparable study sites, Mahalaxmi CF, west of Birienchok, was included. Mahalaxmi is easily positioned along the scale among the other forests in terms of user-density and distance to Gorkha (Figure 3.1).

Differences in terms of explanatory variables enabled me to arrange the forests along a gradient useful for analyses of forest regeneration effected by user-density and market proximity (Figure 3.1). Performing a simple Spearman rank correlation based on these variables (without assigning values), gives r_s=0,203 and p=0.7. Consequently no significant relationship exists. Performing statistical tests and analyses on these variables is thus reasonable as they are not inherently dependent on each other. Background information on the explanatory variables for the included forests is seen in Table 3.1.

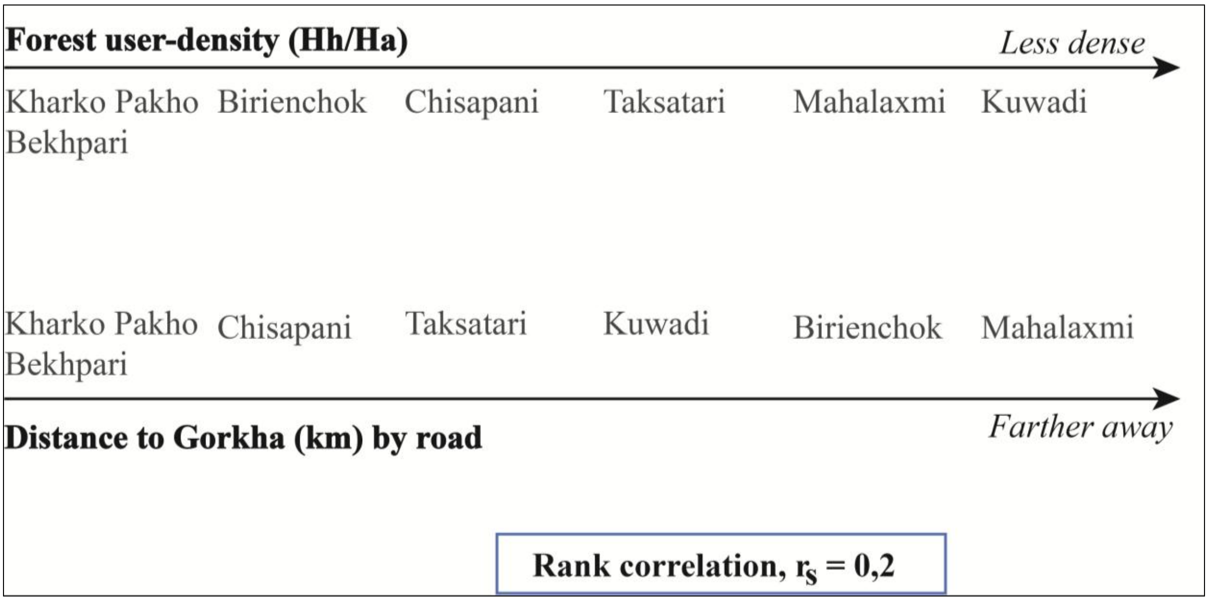


Figure 3.1: The forests have been positioned along a gradient of user-density ($^{Hh}/_{Ha}$) and distance to Gorkha (km) by road. A Spearman rank correlation gives a non-significant association: r_s=0.2, i.e. p>0.05.

Table 3.1: Community forest background information ([1-4]) on variables important for choosing the study site.

CF	Mahalaxmi	Birienchok	Kuwadi	Taksartari	Chisapani	KP Bekhpari
Establishment[2]	1994	1992	1992	1993	1992	1990
Area (Ha)[1]	63.96	83.57	92.27	89.31	50.04	51.15
Households (Hh)[1;3]	71 (pre 2005: *c* 130)	185	120, used by 50 %	105	92	230
User-density = $^{Hh}/_{Ha}$	1.11	2.21	0.65	1.18	1.83	4.50
Distance to Gorkha by road (km)[4] **/ Time to walk (min)**[3]	9.6/120	9.0/100	7.8/60	7.2/60	6.5/90	5.0/30

Information obtained from: [1]ICIMOD; ANSAB; FECOFUN (2010); [2]Operational Plans (Community Forest User Group & District Forest Office 1990-1994); [3] Data gathered from interviews conducted in 2012; [4]GIS estimates on map from ICIMOD (2010).

3.2 Field methods

Fieldwork was carried out in April and May 2012. A systematic sample design was applied to ensure that data collection was carried out unambiguously so that the research questions could be approached in an unbiased fashion.

3.2.1 Systematic plot localization

Fifteen 10 × 10 m plots per forest were located systematically as follows. The north-western border of each forest was located by using map coordinates, Global Positioning System (GPS) and field assistants' local knowledge. At the border, the predefined elevation contour, an "arbitrary" line that cuts through the forest at *c* 660 +/- 20 masl was located. The fixed, limited elevation range was chosen to control for elevation effects, i.e. reduce the potential of change in species composition by change in elevation. The first plot was located *c* 50 m east of the forest border. Relative to this plot the following plots were placed systematically, within the elevation range, between 50 and 100 m from the previous plot (Figure 3.2). Measurement of distances between the plots was done by GPS.

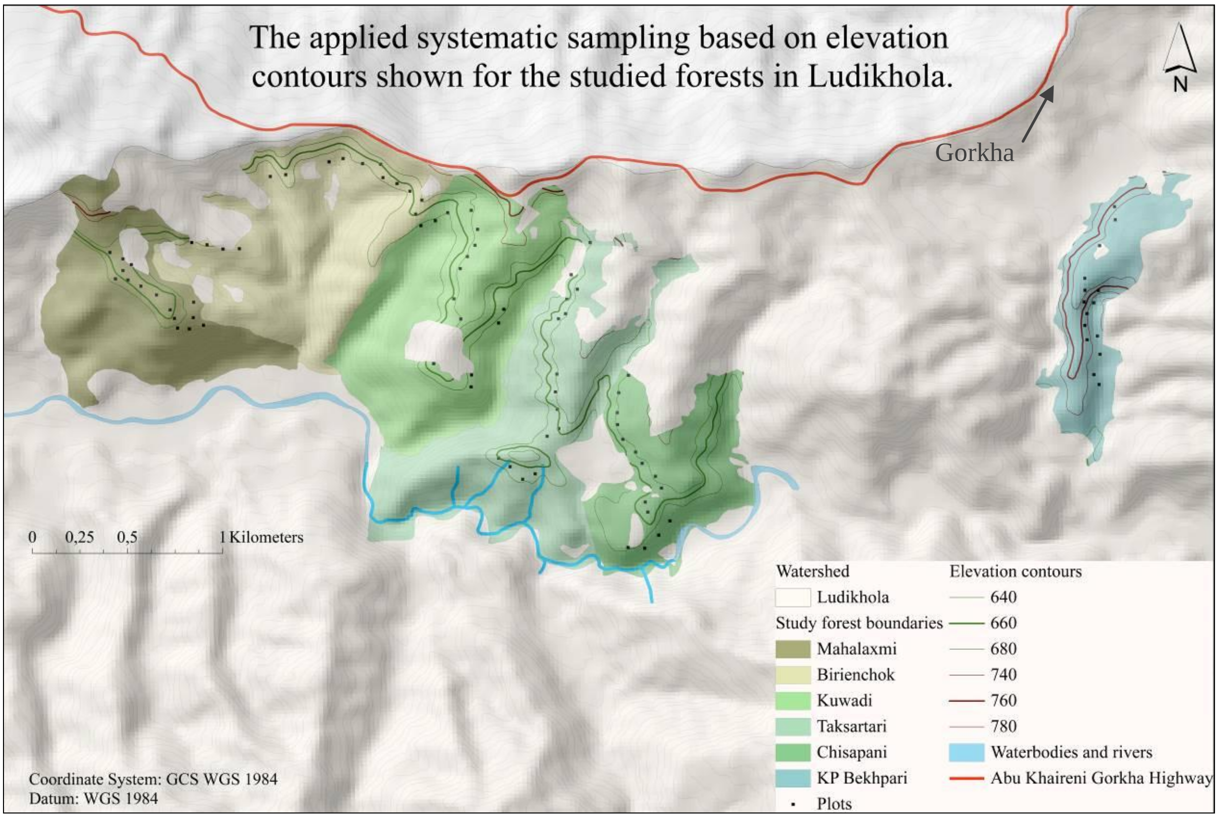


Figure 3.2: Systematic sampling in the studied forests. With the exception of KP Bekhpari where sampling was at *c* 700 to 800 masl, sampling in the other forests was maintained within the same elevation contours, differing about 60 m between the plots.

Exclusion criteria

Due to topographic and anthropogenic features certain areas were impossible or inappropriate to sample. Areas where the following features occurred were consequently excluded (Figure 3.3):

Macro- and micro-topographical features

- Slopes > 40°
- Ravines
- Recent landslides

Anthropogenic features

- Terraces/Farm land
- Construction/Buildings
- Roads/Trails

Sampling was continued systematically 50 m from the eastern edge of the exclusion feature. We recorded the reason for exclusion and measured the distance to the next plot.

Figure 3.3: Features that excluded an area from being sampled. Upper row, left to right: a steep slope dissected by a ravine, farm-construction, old terrace-landscape. Lower row, left to right: a trail used by people and their livestock, rice-cultivated terrace-landscape.

Exception from the predefined contour line

One forest was significantly different from the rest in terms of elevation. KP Bekhpari is situated at around 100 m higher elevation than the other forests further west in Ludikhola. This resulted in a change in the working elevation contour to *c* 740-780 masl (Figure 3.2). Ravines were a more prominent feature of the topography and in areas close to the ravines, the micro-biological climate was clearly wetter. This shift in elevation also indicated a change in the vegetative composition of the forest. S*horea* was still the dominant species, but the abundance of *Schima* was clearly higher than in other forests. Individuals of *Castanopsis indica* were associated with *Schima* in the more humid areas of the forest. Trees of *Castanopsis indica* were not registered.

3.2.2 Plot analysis

Each plot was centred around a mature tree likely to have survived the deforestation period. This ensures that the studied plots are situated in a part of the forest that has undergone several successional stages, i.e. a place that represents the historical context needed for studies of regeneration. The plot size (100 m^2) has been recommended for studies of woodlands as it is likely to provide information both on species patterns and on variation within a sample (Moore & Chapman 1986; Goldsmith 1991 in Waite 2000). The plot size has been successfully used in similar studies (e.g. Vetaas 2000b; Måren & Vetaas 2007). To allow the possibility to analyse micro-scale variation, and to simplify and keep track of the plot procedure, we sub-divided each plot into four quadrats of 25 m^2. They were labelled A, B, C, D clockwise, starting with A, upslope from the centre tree in a north-western direction. By rule it was decided that the centre tree should always belong to sub-plot A. From the centre tree a photo was taken towards the corner of each sub-plot. This was done to secure documentation of each plot and enable post-visualization when needed. In plots where features of specific interest occurred, these were also photographed, resulting in extensive photographic material.

The following description of the plot procedure will successively describe the effects and the possible effects between response and explanatory and co-variables (Figure 3.6). Table 3.2 summarizes key information about the response and all other variables: how they have been defined, the method of measurement, unit and categorization, measurement scale and analysis-extent.

Response variables and land-use related explanatory variables

I hypothesise that forest user-density and proximity to an urban area will change the initial conditions of canopy closure, litter cover, lopping degree, number of cut stems and the fire regime. Hence, they are explanatory variables that by definition are related to land-use.

Regeneration of *Shorea* and *Schima* was studied by number of individuals influenced by an explanatory land-use variable. In each sub-plot the number of recruits—seedlings (individuals < 1.37 m, DBH = 0 cm) and saplings (individuals > 1.37 m, DBH < 5 cm)—were counted. Trees (individuals >1.37 m, DBH ≥ 5 cm) were counted and stem DBH was measured. DBH size-classes are based on Timilsina et al. (2007).

Figure 3.4: Lopping of *Shorea robusta* at different life stages. Right: Seedling heavily lopped and cut; fresh new leaves sprout anyway. Middle: A young heavily lopped tree by the forest trail. Right: Typical example of the long-term effects of lopping on a mature tree. The crown diverges from the expected spreading, spherical crown of undisturbed *Shorea robusta* trees.

Forest canopy is controlled by land-use and recruitment. Microhabitats in forests are largely impacted by local weather conditions such as cloud cover, but also by vegetation. The canopy structure determines not only the quantity and quality of light, but also the spatial and temporal distribution of it. Local precipitation and air movements are also impacted by forest canopy (Jennings et al. 1999). Light can be measured directly or estimated indirectly. Ecologists and foresters often prefer indirect estimates of canopy cover or canopy closure as the direct methods are very expensive and time-consuming (Jennings et al. 1999). In every plot canopy closure, i.e. "the proportion of the sky hemisphere obscured by vegetation when viewed from a single point"

(Jennings et al. 1999 p 62), was visually estimated to the nearest 10 %. Estimation was made from two single points by the same two persons in all plots. One of the two single points was defined as the middle of sub-plot A. Point two differed from one plot to another. When estimates were different, the average of them was registered.

Forest structure can be characterized by several attributes such as age, size, species, horizontal stratification and vertical stratification (Svensson & Jeglum 2001). Such a characterization, independent of attribute, reflects the potential ecology, or the potential ecological diversity. This is again interpreted as an indicator of the viability of the ecosystem (Magurran 1988 in Svensson & Jeglum 2001). In this thesis I focused on one such attribute, namely vertical stratification. This was done to evaluate forest health and regeneration primarily based on anthropogenic disturbance studied through canopy closure, lopping degree and number of cut stems. Vertical stratification and density is a factor that is central in explaining the habitat and ecological processes of a forest (Svensson & Jeglum 2001). Structure based on stratification for the seedling ("shrub") and the sapling layer ("sub-canopy"; saplings and small trees, i.e. not the canopy closure) was therefore taken note of. Both layers in all plots were given separate ranks from 0 – 2 where;

- (0) No layers existed, (1) Shrub layer present, (2) Shrub and sub-canopy layer present

Leaf litter is a term used for fallen leaves lying on the ground. It is a variable that might impact plant establishment because it prevents light from reaching the soil where seeds are likely to be buried. Plant response is dependent on the extent and depth of the litter, which are related to the characteristics of the established species (Molofsky & Augspurger 1992). Leaf litter adds nutrients to the soil system (Schmidt et al. 1993 in Sapkota 2009), and is at the same time argued to be a mechanical hindrance for seed germination and seedling regeneration (Troup 1975b; a). Based on species leaf-fall pattern, leaf litter is to some degree a seasonal variable. Leaf litter in all plots was visually estimated to the nearest 10 % based on the extent of the cover.

Lopping is the process where people cut twigs and collects leaves for firewood and fodder purposes. The direct effects—cut twigs and absence of leaves—are primarily seen on big seedlings and saplings as they are most accessible and consequently most vulnerable. When trees are lopped it is usual to cut branches (Gautam 2001). Long-term effects of lopping are seen in the tree's growth form as it develops in ways that differ from the described natural growth of that specie (Figure 3.4; Figure 2.11). Lopping continues all year around, having its peak during the dry season in March to May when leaves are fresh. Degree of lopping in all plots was subjectively estimated and ranked from 0 – 4 where;

- (0) Not lopped, (1) Slightly lopped, (2) Moderately lopped, (3) Intensively lopped (4) Extremely intensively lopped

Disturbance is also indicated through another variable, namely the number of cut stems per plot. A cut stem was defined as a tree, i.e. estimated DBH ≥5 cm, but less than 1.37 m in height because it was cut. All cut stems were counted regardless of whether they were dead or had new sprouts.

Fire clearly impacts on regeneration. Seedlings and saplings are most exposed and vulnerable to fire (Gautam & Devoe 2006). Recent fires can be detected by identifying burn marks on trees, ash on the ground, burnt destroyed trunks and the lack of one or more stratification layers. In every plot we registered whether or not signs of fire were found.

Physical and biological co-variables

Each plot was georeferenced at the central tree by using GPS. Latitude, longitude and elevation data was saved as a GPS “waypoint” so that it could be imported to Geographical Information Systems (GIS) for map making and to Spatial Analysis in Macroecology (SAM) for various spatial analyses (Figure 3.2). Slope inclination and aspect were measured with a clinometer compass. Humidity was measured in all sub-plots by a pocket device. The average value of the plot was calculated so that each plot had only one value for humidity. The absence or presence of *E. odoratum* and *E. adenophorum*, invasive weeds that might inhibit the establishment of seedlings and displace understorey vegetation (Tripathi & Yadav 1987 in Carpenter 2005), was recorded in every plot. The value 0 was given plots where *Eupatorium* of any type was absent, while plots with presence of *Eupatorium* were given 1.

Figure 3.5: Some of the studied variables. Left: Canopy closure was visually estimated from a single point in sub-plot A. Middle left: A restricted area in KP Bekhpari impacted by a recent fire. The area was excluded from sampling. Middle right: *Eupatorium adenophorum* in flower. Right: litter cover extent consisting primarily of *Shorea robusta* leaves.

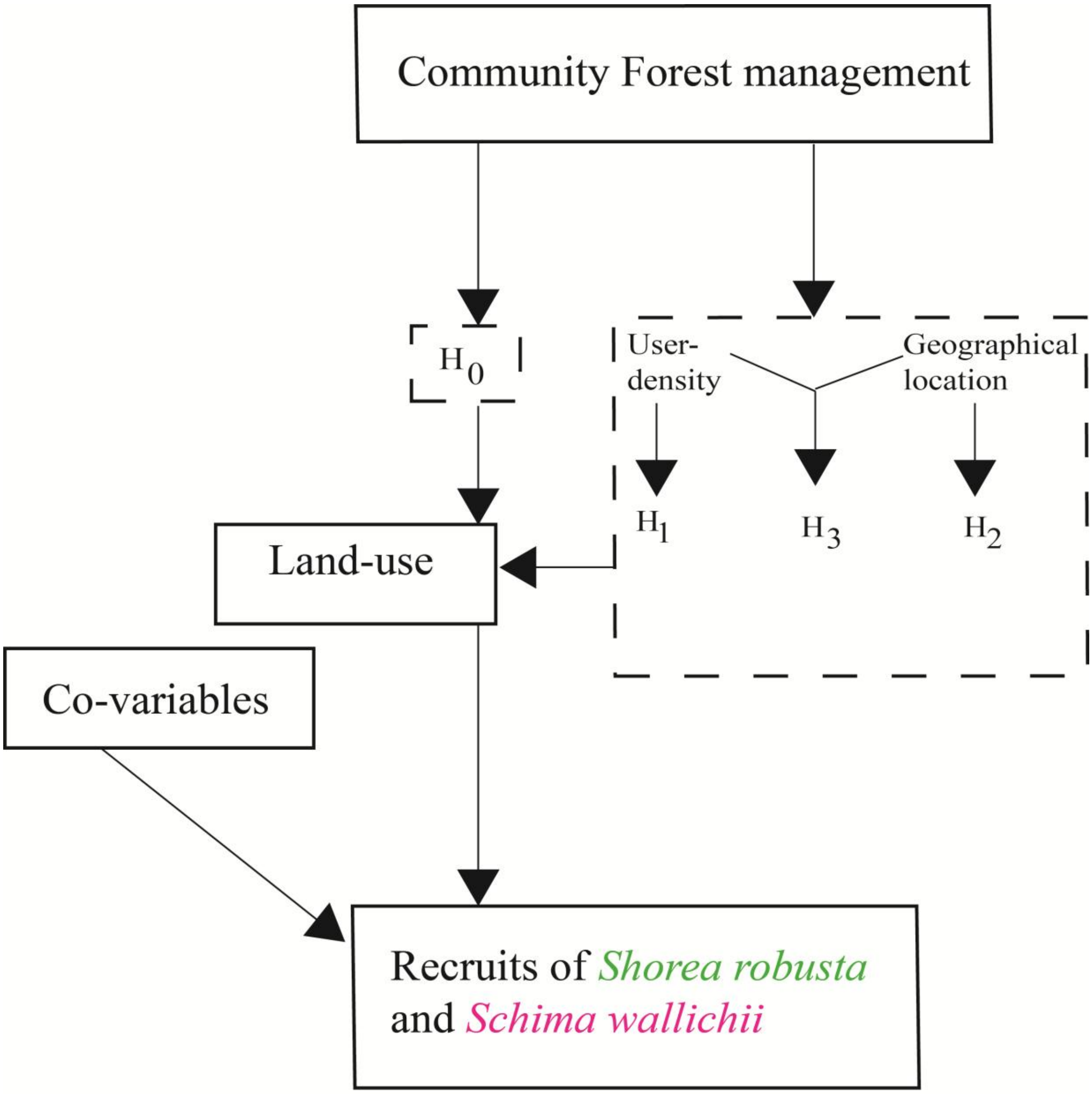


Figure 3.6: System interactions: possible effects of CF on regeneration of *Shorea robusta* and *Schima wallichii*. Regeneration, which is determined by influences from land-use (canopy closure, litter, cover, degree of lopping, number of cut stems) and co-variables (soil moisture, RRI, elevation), may be independent of changes in forests' human-ecological gradients, *cf*. the pathway of H_0. Another possibility is that the intensity of use and thus regeneration is affected by the attributes of the human-ecological gradients *cf*. pathway of H_1-H_3.

Table 3.2: The studied variables; the way they were defined, how and what scale they were measured at and the unit of interest.

Variable	**Definition**	**Method of measurement**	**Unit and categorization**	**Scale of measurement**	**Analysis extent**
Response:					
Trees of *Shorea robusta* and *Schima wallichii*	Individuals >1.37 m, DBH ≥5 cm	Individuals were counted and DBH measured	Number of trees 0 - X DBH = ≥ 5 cm - X	Ratio	Sub-plots
Saplings of *Shorea robusta* and *Schima wallichii*	Individuals > 1.37 m, DBH < 5 cm	Individuals were counted	Number of saplings 0 - X	Ratio	Sub-plots
Seedlings of *Shorea robusta* and *Schima wallichii*	Individuals < 1.37 m, DBH = 0 cm	Individuals were counted	Number of seedlings: 0 - X	Ratio	Sub-plots
Land-use related explanatory variables:					
Canopy closure	”The proportion of the sky hemisphere obscured by vegetation when viewed from a single point” (Jennings et al. 1999 p 62)	Visual estimated within plot boundary. Independent of species composition	Percent	Ratio	Plot
Stratification	Stratification refers to the different layers of plants. In a healthy forest all layers; i.e. shrub, sub-canopy and canopy, shall be present.	Visual estimated. Shrub-layer and sub-canopy were estimated separately from canopy closure	0: No layers existed 1: Shrub-layer present 2: Shrub- and sub-canopy layer present	Ordinal	Plot
Ground litter cover	Extent of leaf litter at ground	Visual estimated	Percent	Ratio	Plot

Degree of lopping	Outtake of leaves and twigs by humans for fodder and firewood purposes	Visual estimated	0: Not lopped 1:Slightly lopped 2:Moderately lopped 3:Intensively lopped 4: Extremely intensive lopped	Ordinal	Plot
Number of cut stems	Trees and saplings that has been cut. Cut stems up to 1.37 m were registered	Individuals were counted	Number of cut stems 0 - X	Ratio	Plot
Fire	Signs of fire either ignited by humans or by natural occurrence	Plot inspection Interviews	0: Absent 1: Present	Nominal	Plot
Physical co-variables:					
Plot location	Geographical coordinates: latitude, longitude, elevation	Global Positioning System (GPS) and map	Degrees, minutes, seconds Masl		Plot
Slope	Inclination Aspect	Clinometer compass Clinometer compass	0 – 90 degrees 0 – 360 degrees	Ratio Ratio	Plot Plot
Soil	Humidity	Pocket device - ELIT PMS-714	Percent	Ratio	Sub-plots
Biological co-variables:					
Eupatorium odoratum and/or *Eupatorium adenophorum*	Weeds that might inhibit establishment of seedlings and displace understorey vegetation (Tripathi & Yadav 1987 in Carpenter 2005)	Plot inspection	0: Absent 1: Present	Nominal	Plot

3.2.3 Qualitative approach in the field

Contextualization was the main purpose for using qualitative methods. The rationale was that semi-structured interviews, observation and field conversations would deepen my understanding of those patterns outlined by performing statistical analyses. Focus was particularly directed on understanding to what degree CF management regulates the use of forest products that may enhance regeneration. I used interviews, field conversations and observations to discover what rules for forest-product use each CFUG had decided upon; how these rules were followed-up by the CFUG and to what degree these rules were obeyed by the users.

Semi-structured interviews

We used semi-structured interviews to explore and understand the rules and practices of the CFs. Semi-structured interviews are ‘soft’, informal, conversational and only partially structured in that participants use their own words in the response and open interactions between the involved parts are prominent (Nicholas et al. 2010). Questions were prepared beforehand and I went through them with my field supervisor and interpreter to discuss, revise, and clarify subjects and formulations before they were posed. Respondents were introduced to the topic and the research objective before they agreed to participate. No one was reluctant to be interviewed. A total of seven semi-structured interviews were conducted during field work. In addition to one interview with the DFO, leaders of all the CFUGs (Figure 3.8) were interviewed.

Field conversations

Field conversations take the form of an everyday conversation between people. Comments from such, often spontaneous and unsolicited, may turn out to be essential for the researcher (Aase & Fossåskaret 2007). Field conversations were not planned but came into being as we talked with forest-users and others we met in the forest. The conversations were informal and comfortable discussions concerning subjects primarily decided by those we spoke to. At times we focused the discussions on the forest activity they were engaged in, such as carrying animal fodder (Figure 3.7), herding or logging as this was interesting for the study purpose.

Figure 3.7: Conversation about fodder species with forest-users in KP Bekhpari. It is clear from the collected products that *Schima wallichii* is an important species in KP Bekhpari.

Observations

Observations concern both visual impressions and conversations (Aase & Fossåskaret 2007). The researcher either take an "active" role by taking part in the interaction being studied, i.e. participant observation; or a "passive" role by being present but not participating and interacting, simply known as observation (Aase & Fossåskaret 2007). I used participant and simple observation to get an impression of the degree to which the forest users we met acted according to the rules portrayed by the CFUGs.

Qualitative complexities and how they were addressed in the field

When studying a culture different from one's own, there are a number of difficulties and complexities that may be encountered and dissimilarities to be aware of. The interpreter introduced me and my study objective very properly to those people we interacted with. This was crucial as my role—a western female student—deviates quite strongly from what is expected from cultural practices in Nepal. Suspiciousness towards the study and reluctance to participate was almost non-existent, a fact that should be credited to the interpreter who interacted very well with the various informants.

Because of the language barrier my field supervisor and interpreter did the talking. He translated on-the-go and comprehensive notes were taken. This enabled me to follow up with questions and directing the conversations on interesting subjects brought up. I focused on making comprehensive notes of observations, interview contexts and other things that could provide additional information to my study, even if at the time it seemed irrelevant or insignificant for the analysis.

Figure 3.8: Interviewing leaders and headmen of CFUGs from Kuwadi and Taksartari at hotel Gorkha Bisauni.

3.3 Post-field: the analytical path

The analytical path describes how data from the field, both quantitative and qualitative, has been handled in the post-field situation. It describes the use of numerical methods, as well as the analysis approach used to contextualize qualitative findings.

3.3.1 Numerical methods

Numerical data from 90 sampling plots from among six comparable forests underwent statistical analysis. The main goal of using numerical analyses is to evaluate the research questions by testing the associated hypotheses (H_1-H_3) against the null hypothesis (H_0) with inferential statistics.

Response and explanatory variables were described statistically. Descriptive statistics make no inferences on the statistical population and this section presents untransformed variables. It gives insights to help decide which are the appropriate analyses to perform, and whether certain variables need to be transformed.

Prior to analysis all response variables were square-root transformed. Transforming data means converting raw values to a mathematical derivative, a process which may stabilize the variance and remove dependency upon mean (Fowler et al. 1998). Square-root transformation is a normal transformation for count data (McDonald 2009) which often entail non-normal distributions (Fowler et al. 1998), and/or heteroscedastic characteristics (McDonald 2009). Transformation was performed to allow the use of parametric tests (e.g. correlation, regression and ANOVA analyses) on the variables by increasing homoscedasticity, normality *and* to reduce the influence of outliers (McDonald 2009). Explanatory and co-variables were not transformed due to their rather normal distributions.

Important notes for the various analyses: As there were few *Schima* individuals, seedlings and saplings were combined into ‘recruits’. Most analyses and figures of *Schima* therefore concern recruits solely. *Schima* in other growth stages are not show. Missing values of litter cover in plots 61 and 62 were replaced by variable mean values as deemed necessary. *Shorea* trees are portrayed in tables for correlation, regression and multiple regression analyses as they are used as both an explanatory and a response variable. Note also that when I refer to of number of individuals this is an expression of abundance/density as individuals are divided by the plot size.

Spearman’s rank correlation coefficient (r_s) (Fowler et al. 1998) was used to correlate the CFs according to ranks based on their characteristics of user-density and proximity to Gorkha (Figure 3.1) This was done to ensure that the forests were not similar in terms of these variables and hence, comparable. Correlations between the variables in each of the response, explanatory and co-variable categories were assessed by Pearson’s product moment correlation coefficient, *r*, *cf*. Fowler et al. (1998). The results are presented in correlation matrices. Although correlation does not imply causation, variables that have strong internal correlations should be used with caution in regression analysis (Fowler et al. 1998). I considered variables to be collinear when $r>0.8$, and this was taken into consideration in stepwise forward selection. It may reduce the problem of multicollinearity (Vetaas & Ferrer-Castán 2008).

Response variables were plotted against the explanatory variables in a scatterplot for visual inspection of co-variation. They were then tested for significant associations by Pearson’s correlation. If a significant correlation was found, the association was tested with linear regression to determine which conditions favoured recruit germination and establishment. Variables that entailed associations not reflected by 1st order linear regression were tested for significant non-linear associations by raising x into powers up to the third order (2nd order: quadratic; 3rd order: cubic) conferring Fowler et al. (1998) and McDonald (2009). Regression analyses outline the direction of the relationship and the proportion of variance in the response variable that is accounted for by the variance in the explanatory variable (R^2) (Fowler et al. 1998).

Trees were analysed based on forest structure, and species size-class distributions were portrayed in DBH histograms. This was done at two levels: first to represent overall forest regeneration, and second to describe forest-specific regeneration. The negative exponential function and the power function were fitted to the DBH size-class distributions. This was done to check if linear regressions accounted for the observed diameter distribution (Leak 1964; Harcombe & Marks 1978; Hett & Louks 1976 in Vetaas 2000b).

RRI was estimated to elucidate the relationship between the response variables and the combined effect of slope inclination and aspect (slope azimuth). RRI expresses the mean annual radiation received at a site(Oke 1987; Vetaas 1992). It is calculated as a function of latitude, slope inclination and aspect, and expressed as: RI = *f* (latitude, slope inclination, slope aspect) (Oke 1987). RI is an index that expresses the annual mean sun radiation at noon (12:00) at a specific location. RI is calculated with the following algorithm:

$$\cos \Theta = \cos \beta \ \cos Z + \sin \beta \sin Z \cos (\Omega - \hat{\Omega}),$$

where: Z = zenith angle, β = slope angle, Ω = solar azimuth angle, $\hat{\Omega}$ = slope azimuth angle, Θ = angle of incidence (between the sun and the normal to the slope) (Oke 1987). The index ranges from 0 = no radiation to 1 = maximum radiation (i.e. obtained on a slope with a direct southern aspect 180°, where the slope inclination degree is equal to latitude where the sun is in the zenith at noon). Note that factors such as cloud cover, the atmospheric coefficient and topographic shading have not been accounted for: this limits the index results (McCune & Keon 2002).

I used multiple regressions to check if variance in the response variable was better explained (indicated by increasing R^2) when more variables were added as predictors to the equation. Multiple regressions adds another variable to the regression equation and it can be applied in linear or curvilinear regression if designated a second or third power (McDonald 2009). Multiple regression was performed using a forward stepwise R^2 criteria *cf*. Austin (1990). A forward instead of backward elimination was chosen because the forward procedure does not require a 'complete model' that involves all factors and variables as backward elimination does. 'Complete models' are ecologically inappropriate since all possible factors and variables have not been included in the analysis (Austin et al. 1990). A best-fit model for each response variable was made.

I used geographical coordinates and calculated Moran's *I* as a measure of spatial autocorrelation. Spatial autocorrelation is part of geostatistics and based on Tobler's first law of geography (1970 p 236) which states that "(…)everything is related to everything else, but near things are more related than distant things". "Biogeography is spatial by nature" (Hawkins 2012 p 1) and the concept of distance decay therefore interesting. Spatial autocorrelation was re-defined by Legendre (1993 p 1659) as "the property of random variables taking values, at pairs of locations a certain distance apart, that are more similar (positive autocorrelation) or less similar (negative autocorrelation) than expected for randomly associated pairs of observations". Biological processes operate in a spatially patterned environment and species distribution is determined by such processes (Hawkins 2012). This becomes a problem as many statistical tests assume independence between variables, an assumption clearly violated by autocorrelated data (Legendre 1993). It arises from this that spatial data may be misinterpreted because the results are perceived as stronger than they really are (McManus et al. 2012). In spatially autocorrelated data, the number of degrees of freedom is overestimated and the confidence intervals consequently too narrow (Rangel et al. 2006). This inflates the risk of making Type I errors (Legendre 1993; Rangel et al. 2006). Spatial autocorrelation is detected by studying the residuals of a regression. Residuals that lack independence among themselves, i.e. they are *not* randomly distributed, reflect data with spatial trends (Hawkins 2012). I tested for autocorrelation to take account of the location of the community forests and species distributions in geographical space. Here I take the 'residual approach', i.e. testing for remaining spatial structure in residuals posterior to testing the predictor (Hawkins et al. 2007), by calculating the Moran's *I* correlation coefficient. If the residuals showed a significant level of Moran's *I*, then I assumed that the regression model was incomplete. This might be due to missing explanatory variables (Hawkins et al. 2007; Cressie 1993 in Mauricio Bini et al. 2009). If the response variable entailed a significant spatial pattern it was regressed with the multiple regression model to see if it increased R^2, i.e. removed the impact of the spatially inherent trend in the variable.

Differences between each forest's regenerative behaviour were tested as a direct cause of land-use (H_1–H_3). I used ANOVA analysis (Fowler et al. 1998) to test if the mean number of response variables and the mean value of explanatory variables were significantly different between the six forests. To obtain detailed information on which forests were significantly different from the others, a Tukey-test (McDonald 2009) was performed to identify which variable means are different from each other. Boxplots portray the differences between the forests in terms of land-use variables. In cases where only two groups were compared I used a *t*-test.

Significance (*p*) was set at or below the 0.05 level for all tests. Significant values were indicated by **bold face** in tables. All statistical/geographical analyses were carried out using the following computer programs:

- PASW Statistics (former SPSS), v. 18.0 (SPSS Inc 2009).
- Spatial Analysis in Macroecology (SAM), v. 4.0 (Rangel et al. 2010). Described in Rangel et al. (2006).
- Arc GIS (ESRI 2012).

3.3.2 Qualitative

Clean copies of all interviews were made within a reasonable time to ensure as little information as possible was lost. Reflections of interview-context and progress were also noted down when I returned from the field. As only discrete notes were taken during field conversations and of observations, details were added afterwards.

To use an interpreter always introduces the risk of misunderstandings and possible mistranslations, even if the translator has good English and scientific skills. To minimize the degree of such misunderstandings in the material the translator and I went through the clean copies of interviews and also discussed observations. This was very useful as vagueness could be explained and missing details filled in. This process also served as a reminder of things and practices I questioned in the field.

During analysis, information obtained through interviews, conversations and observations were put together and plausible conclusions were reached.

The aim is that results from numerical analyses, together with qualitative information shall enable sound conclusions concerning forest regeneration and reduce the probability of making type I or type II errors, rejecting a null hypothesis that is true, and accepting a null hypothesis that is false, respectively (Fowler et al. 1998).

CHAPTER 4 RESULTS

4.1 Numerical results

4.1.1 Descriptive statistics and distribution of variables

Response, explanatory and co-variables were described by means of simple descriptive statistics and graphics to outline features of specific interest.

Response variables

Shorea's abundance in all life stages is dominant and abundant in comparison to *Schima's* whose abundance is much more restricted (Figure 4.1). A total of 12 391 individuals was counted, of these 11 392 *Shorea*. The number of seedlings, compared to that of saplings and trees is, as expected in sustainable forests, significantly higher for both species. With respect to the current number of individuals, 20 % of *Shorea* seedlings survive to saplings, while for *Schima*, 42 % survive to the sapling stage. While only 20 % of *Shorea* individuals are lost from the sapling to tree life stage, the loss is much higher for *Schima* (40 %). Both species have a survival-rate from seedlings to trees of ~15 %, although the life stage at which individuals are lopped and dies, or cut differs between the species.

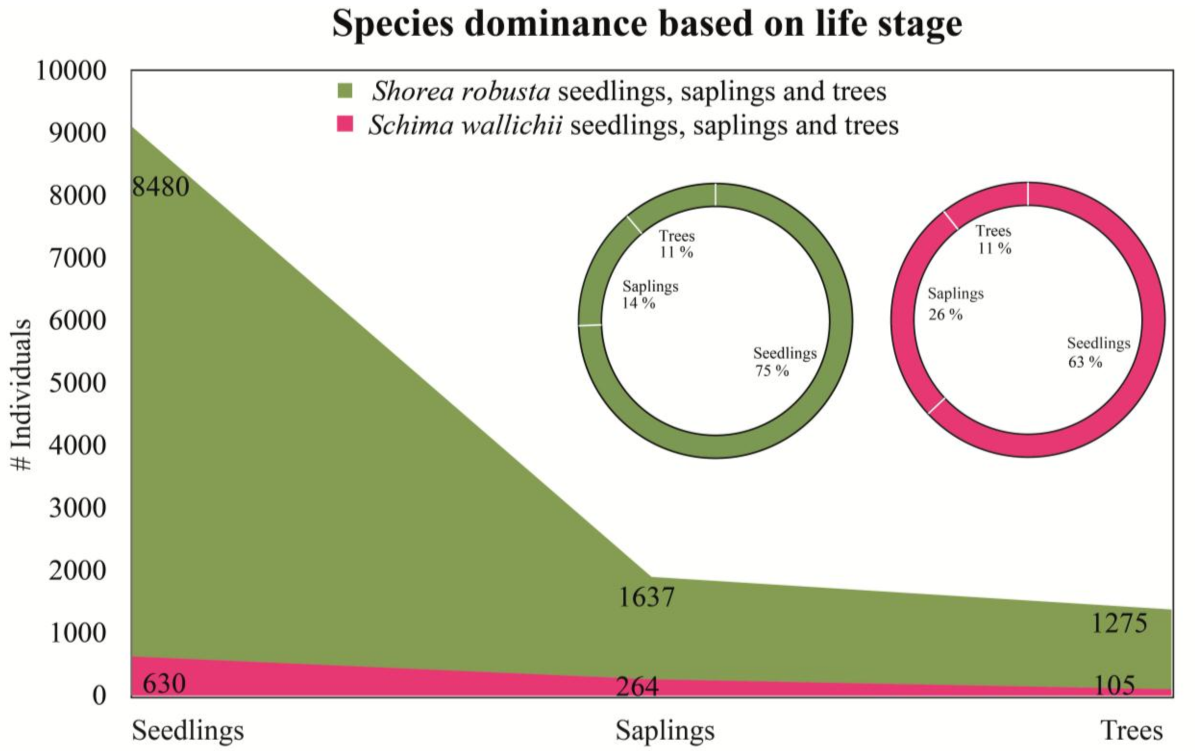


Figure 4.1: Main figure depicts *Shorea robusta* and *Schima wallichii* counts in seedling, sapling and tree life stage. The circles refer to the percentage of the total population held by each life stage.

Details of response variables in the different life stages are given in Table 4.1 and Figure 4.1. The range of *Shorea* compared to that of *Schima* is much greater. *Schima* is absent from more than five plots at all life stages, compared to *Shorea* which is only absent from a few plots at the sapling life stage. The standard deviation, standard error and variance are therefore much larger for *Shorea* than *Schima*. Life stage counts per plot for both species are shown in Figure 4.2. *Shorea* (Figure 4.2 I) seedlings have an extensive range compared to the other life stages. The range and variance of *Shorea* saplings, compared to trees, is much larger even though the median is close to similar, respectively 12 versus 13 individuals. *Schima* (Figure 4.2 II) also has its largest range within the seedling life stage, but it is far less articulated than that of *Shorea*. What is remarkable with *Schima* is the high number of extreme and moderate outliers despite the relatively restricted data range.

Table 4.1: Descriptive statistics for I) *Shorea robusta* and II) *Schima wallichii* individuals for all the plots (N=90).

	# Ind	Range	Min	Max	Mean	Std.Error	Std.Dev	Variance	Skewness	Kurtosis
I) *Shorea robusta* – all forests										
Seedlings	8480	223	16	239	94.22	5.433	51.544	2656.804	0.865	0.336
Saplings	1637	68	0	68	18.19	1.695	16.077	258.470	1.124	0.776
Trees	1275	35	3	38	14.17	0.785	7.445	55.421	0.990	1.399
II) *Schima wallichii* - all forests										
Seedlings	630	42	0	42	7.00	0.808	7.669	58.809	2.394	7.234
Saplings	264	16	0	16	2.93	0.341	3.235	10.467	1.751	3.313
Trees	105	9	0	9	1.17	0.162	1.538	2.365	2.424	7.926

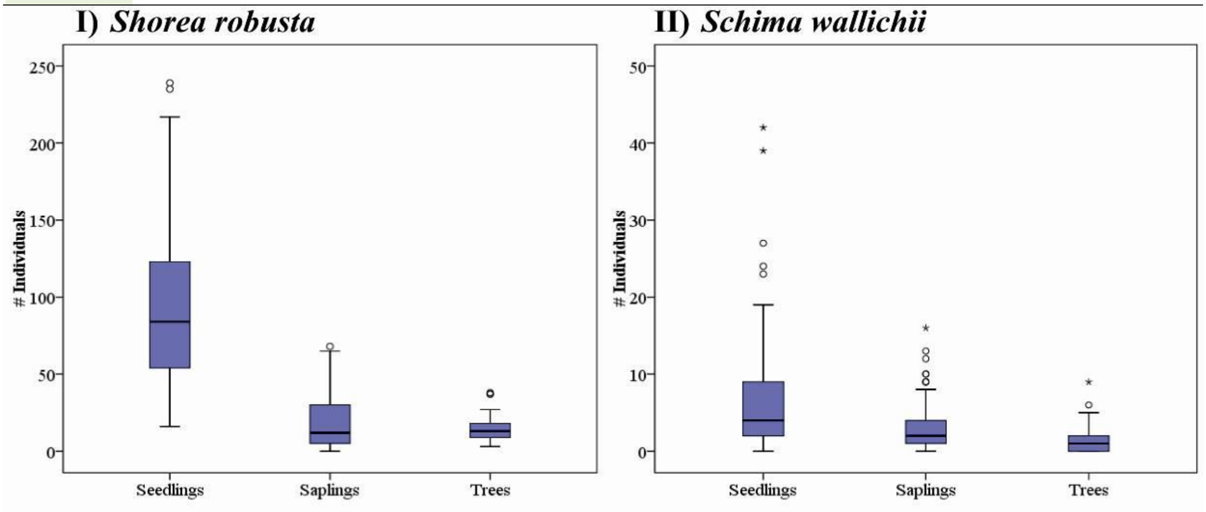


Figure 4.2: Median, range and outliers of counts of I) *Shorea robusta* and II) *Schima wallichii* individuals per plot at various life stages. Note different scales on the y-axis. Boxplot characteristics: Upper line, maximum; lower line, minimum; lower box edge, 1st quartile; upper box edge, 3rd quartile; thick line within box, median; ○ outlier; *extreme outlier.

Histograms of the raw count data plotted alongside a normal curve (Figure 4.3; Figure 4.5) may indicate if transformation is needed.

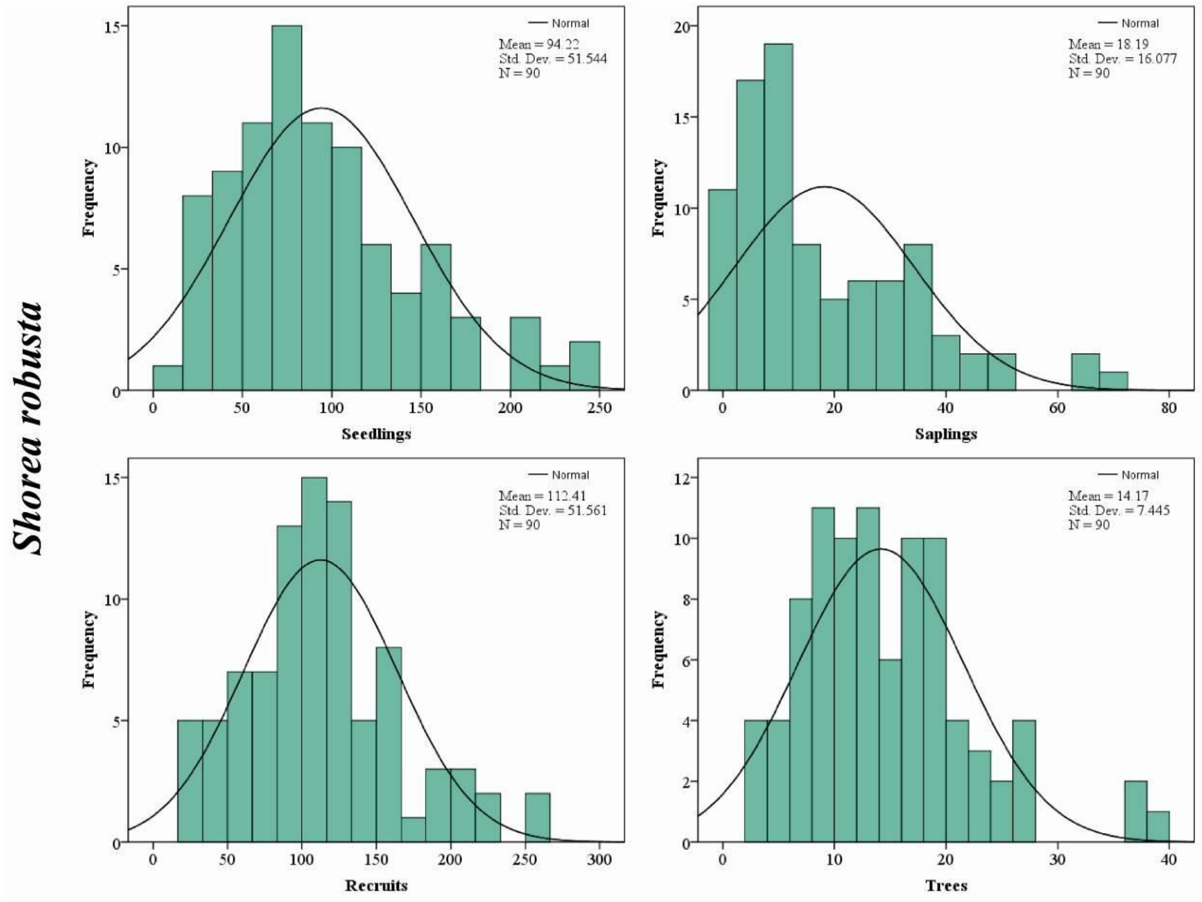


Figure 4.3: Histograms with normal curve for raw *Shorea robusta* count data. Note different scales on the y-axis.

Shorea (Figure 4.3) seedlings have a slight positive skew of 0.865 and a kurtosis of only 0.336. It is hence are the variable that most closely conforms to the normal distribution. This is expressed through the average value, variation, skewness and kurtosis of the distribution. Saplings have a greater positive skew (1.124) than seedlings and trees. It illustrates that there are fewer plots with many individuals. Zero-values of *Shorea* saplings were observed in four plots. The mode, 9, is different from the mean, 18, and the median, 12. Recruits show a relatively normal distribution. The mean is 112 individuals per plot, and the median and mode is within ±10 individuals. *Shorea* trees were present in all plots. The most frequent value of trees is between six and twenty per plot, with a significant decrease in number of plots with more than 20 trees. This results in a histogram with a rather flat shape, illustrated by an index of kurtosis at 1.399. Some plots diverge from other plots by having a particular high occurrence of trees, around 36-40 per plot.

Square-root transformation of *Shorea* (Figure 4.4) counts normalized the data so that the assumptions for parametric tests in terms of homogeneity and homoscedasticity were met.

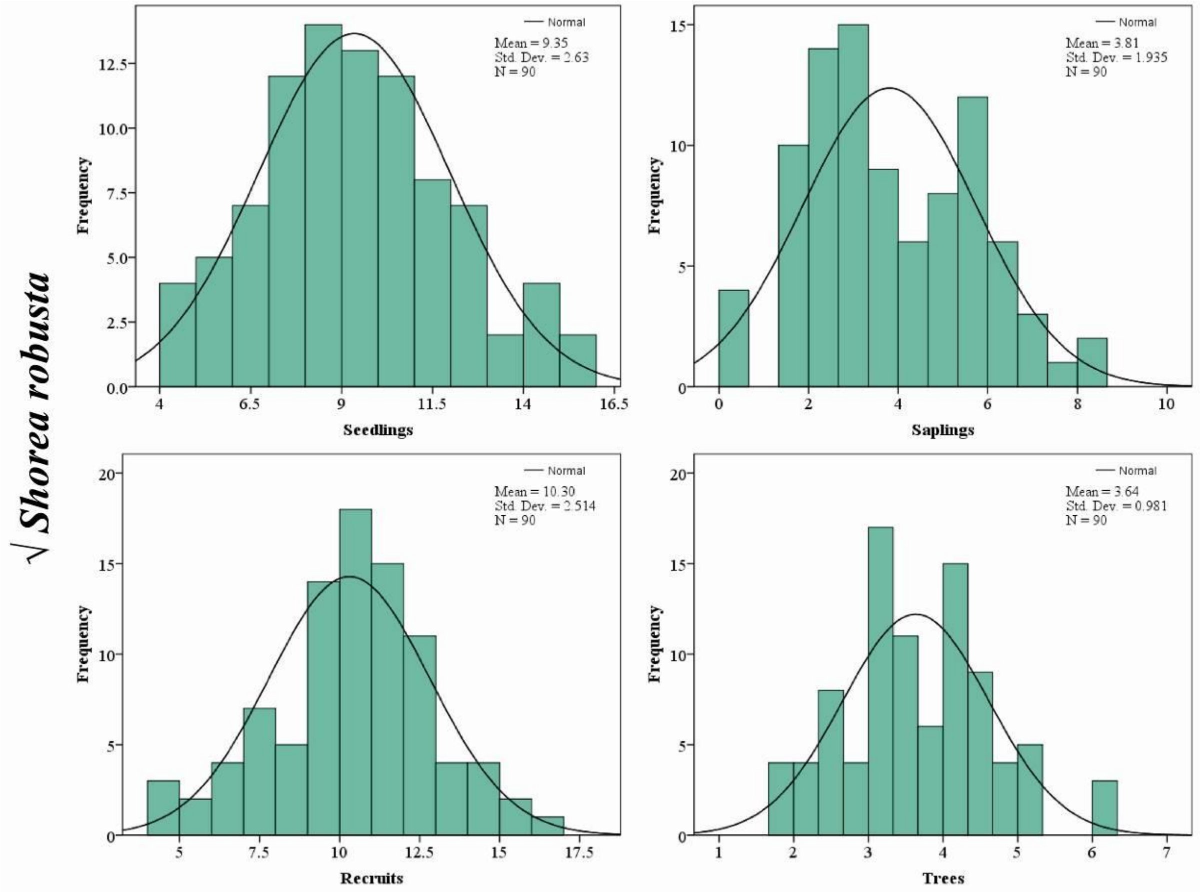


Figure 4.4: Histograms with normal curve for square-root transformed *Shorea robusta* count data. Note different scales on the y-axis.

Histograms of *Schima* (Figure 4.5) show that the data are Poisson distributed, i.e. positively skewed values that decrease with larger frequency of individuals per plot. The mean value of seedlings per plot is seven. It diverges from the median and the mode of four. Very few plots have more than 13 seedlings, although the maximum is 42. This results in a large range and a highly skewed distribution (2.394). The high number of plots with few seedlings results in a relatively flat curve with a kurtosis index of 7.234. The distribution of saplings is not as skewed (1.751) as seedlings because the range of values is lower. Mean saplings, 2.93 per plot is similar to the median of 2. Trees are even fewer in number. The range is zero to nine, but most plots count only one individual (mean 1.17, median 1). The distribution is highly skewed (2.424) and the kurtosis index 7.926 is a result of the high frequency of plots with only few individuals.

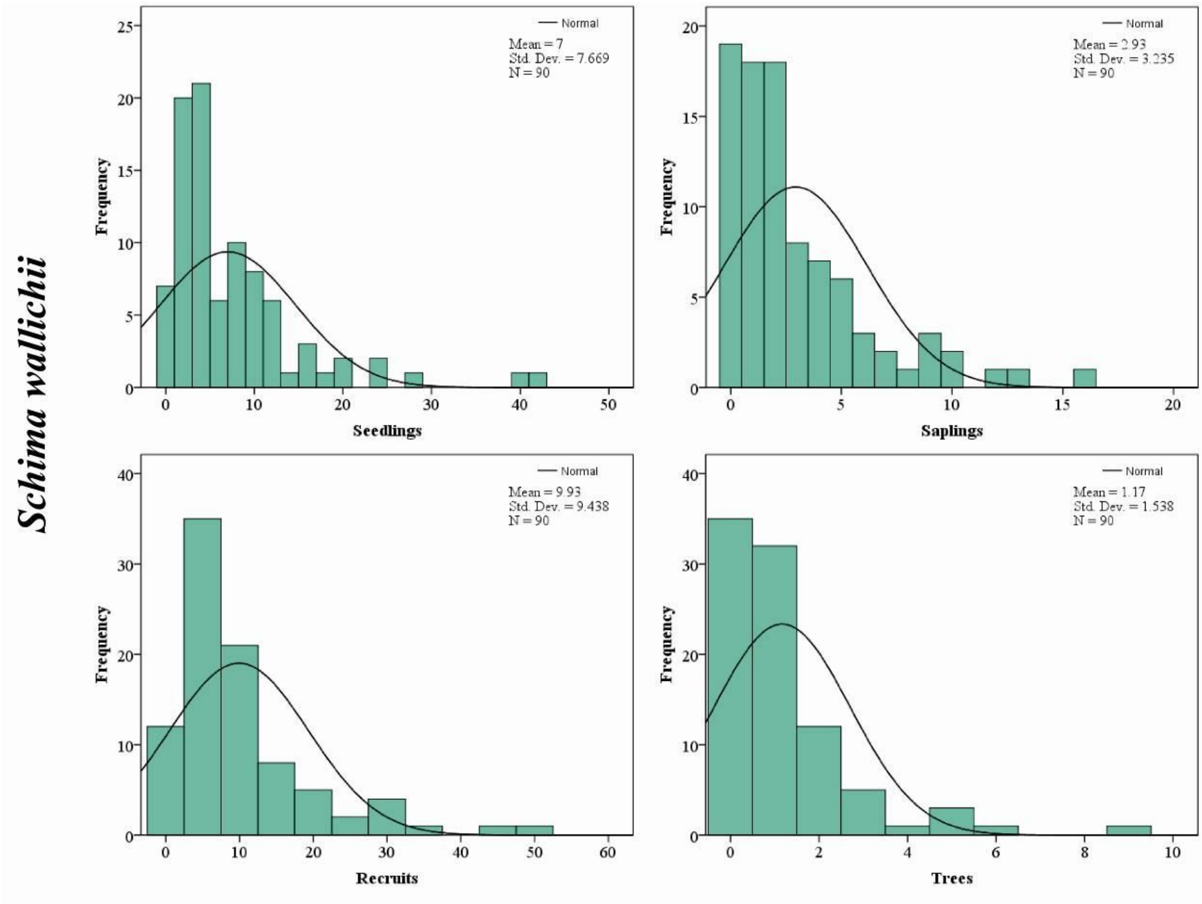


Figure 4.5: Histograms with normal curve for raw *Schima wallichii* count data. Note different scales on the y-axis.

All values of *Schima* were square-root transformed (Figure 4.6). Transformation resulted in a better fit to the normal curve, although still slightly Poisson-distributed. The small number of *Schima* individuals (Figure 4.1) limits what can be inferred about the population at the different life stages. I consequently decided to combine seedlings and saplings into a recruits category, representing 90 % of the counted *Schima* individuals. Note here that seedlings are overweighted in this analysis as they represent 70 % of the recruits. When the recruits category was square-root transformed it was approximating a normal distribution (Figure 4.6), and it could thus be used in inferential statistics.

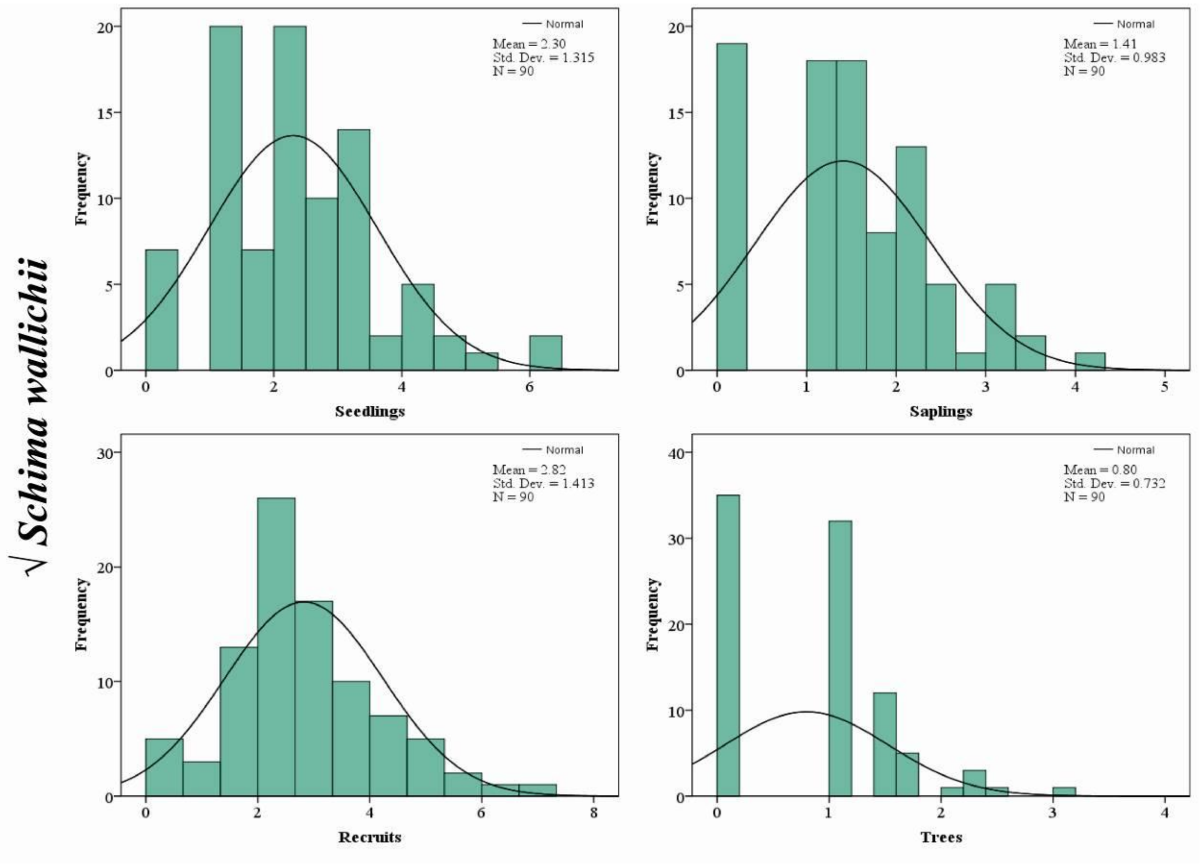


Figure 4.6: Histograms with normal curve for square-root transformed *Schima wallichii* count data. Note different scales on the y-axis.

Land-use related explanatory variables

Histograms of explanatory variables showed that number of plots in each percent interval is not equal, but normally highest around average (Figure 4.7). Table 4.2 describes the variables.

Table 4.2: Descriptive statistics for land-use related explanatory variables for all the plots (N=90).

	N	Range	Min	Max	Mean	Std.Error	Std.Dev	Variance	Skewness	Kurtosis
Canopy (% cover)	90	70	20	90	49.89	1.608	15.250	232.572	0.175	0.241
Litter (% cover)	90	40	60	100	80.00	1.048	9.944	98.876	0.000	-0.842
Lopping (intensity class)[1]	90	3	1	4						
Cut-stems	90	14	1	15	6.09	0.312	2.955	8.734	0.817	0.705

[1]: Note: Lopping is an ordinal variable (Table 3.2), thus the descriptive statistics are only given for min and max.

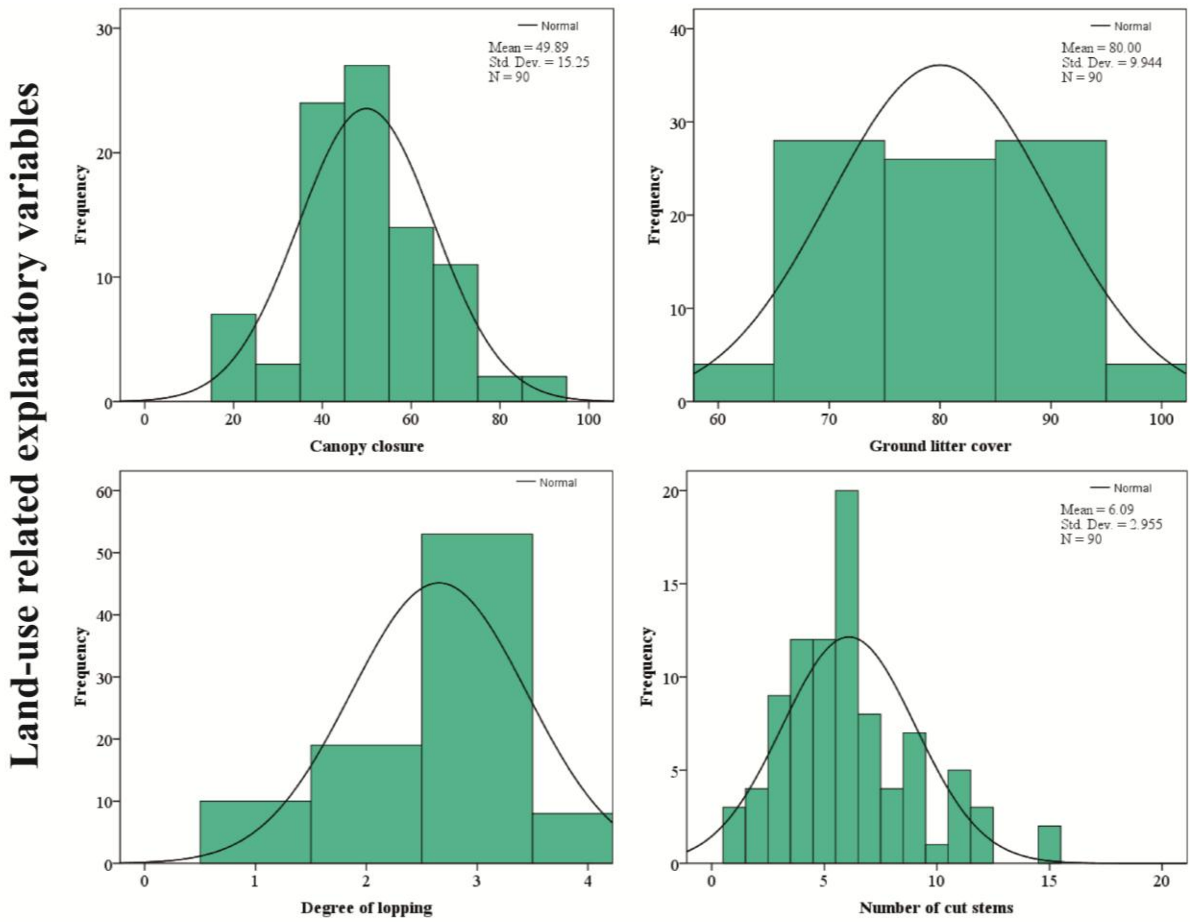


Figure 4.7: Histograms with normal curve for land-use related explanatory variables. Note: Lopping is an ordinal variable (Table 3.2), thus the assumptions of continuous variables are violated.

Canopy closure has a range of 70 %, stretching between a minimum of 20 and a maximum of 90 %. Closure between 40 and 60 % (70 %) is the most common, reflected by the mean, 49.9 % and the median, 50 %. Relatively few plots have a closure that is below 40 and above 70 %. Canopy closure has a relatively good fit to the normal curve. Litter cover has a much more limited range than canopy closure. It varies from 60 to 100 %, with almost all of the plots between 70 and 90 % litter cover. Its distribution is asymptotic, i.e. there is no skew because the numbers of plots at either end of the histogram are similar. Lopping was categorized by intensity from 0 – 4, and the observations ranged between 1 and 4 with a mode of 3. Note that this variable does not follow the strict assumptions of inferential statistics and have a primarily descriptive value to guide the interpretation of causal links.Cut stems range between 1 and 15. More than 20 % of the plots hold the mean value of 6 cut stems. Three plots deviate from the rest with 15 cut stems, a number significantly higher than that for the other plots. Signs of fire in plots were rare and date long back. This variable was therefore taken out of the quantitative analysis.

Co-variables

Co-variables are factors that may affect response variables but which are not influenced by the land-use system directly. An ideal sampling would be free from co-variables. In mountainous areas it is however impossible to avoid variation, and co-variables were measured to account for the influence they might have on species responses. As these are not of direct interest I will not explain their characteristics in much detail. With regard to the co-variables it is sufficient to look at their features (Table 4.3;Figure 4.8).

Table 4.3: Descriptive statistics for physical co-variables for all the plots (N=90).

	N	Range	Min	Max	Mean	Std.Error	Std.Dev	Variance	Skewness	Kurtosis
Elevation	90	158	628	786	670.10	4.583	43.478	1890.338	1.605	1.117
RRI	90	0.418	0.581	0.999	0.843	0.011	0.111	0.013	-0.475	-0.667
Soil moisture	90	8.650	0.125	8.775	3.325	0.240	2.274	5.171	0.254	-0.644

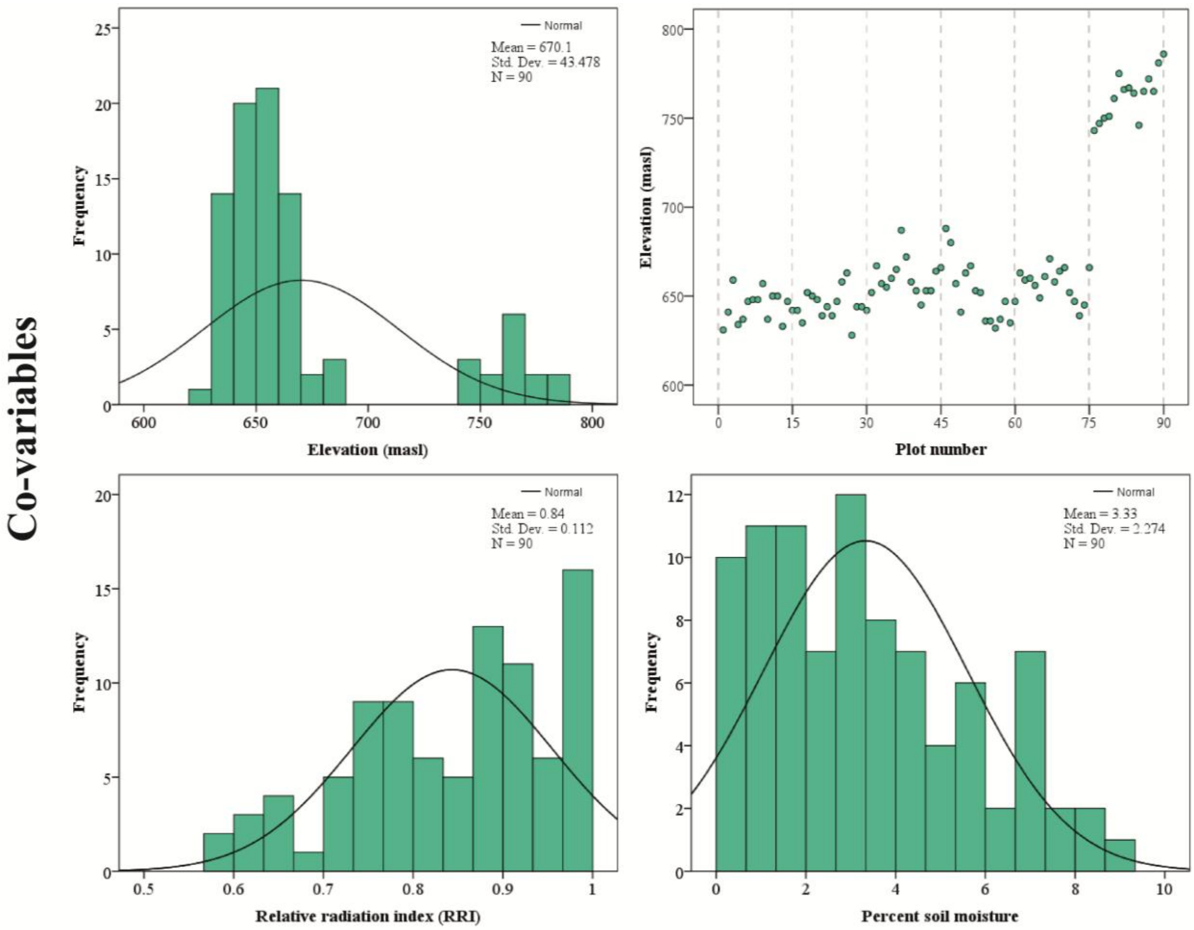


Figure 4.8: Histograms with normal curve and scatterplots for physical co-variables.

From the elevation data we can see that most of the plots are within a range of 640 to 670 masl. Some of the plots (15) are however at a higher elevation, between 740 – 790 masl. RRI varies on a scale from 0.581 to 0.999 and has a mean of 0.843, i.e. none of the plots are on slopes facing directly north. Soil moisture varies from *c* 0.1 to 9.0 %. The mean is 3.3 % and the distribution is positively skewed.

The biological co-variables, *E. odoratum* and *E. adenophorum*, were taken out of the analysis because individuals were only found in one plot, i.e. they did not inhibit regeneration of *Shorea* and *Schima*.

4.1.2 Correlation matrices between variables

Variables of the same category (response, explanatory and co-variables) were tested for significant internal correlations. Studying interactions between variables may indicate relationships that play an important role in explaining the results.

Table 4.4: Pearson two-tailed correlation coefficient (*r*) between square-root transformed response variables. N = 90. **Bold face** denotes significant *p*-value, i.e. $p \leq 0.05$ for $r \geq 0.205$, $p \leq 0.01$ for $r \geq 0.267$.

		√ *Shorea robusta*				**√ *Schima wallichii***			
		Seedlings	Saplings	Recruits	Trees	Seedlings	Saplings	Recruits	Trees
√ *Shorea robusta*	Seedlings	1	-0.084	**0.946**	**-0.307**	**-0.261**	**-0.260**	**-0.294**	-0.128
	Saplings		1	**0.229**	0.203	-0.030	-0.057	-0.060	**-0.236**
	Recruits			1	**-0.213**	**-0.254**	**-0.280**	**-0.301**	**-0.220**
	Trees				1	-0.025	-0.013	-0.004	-0.200
√ *Schima wallichii*	Seedlings					1	**0.432**	**0.944**	**0.234**
	Saplings						1	**0.688**	**0.241**
	Recruits							1	**0.286**
	Trees								1

Response variables

Trees of *Shorea* (Table 4.4) correlate negatively with seedlings (*r*=-0.307) and consequently recruits (*r*=-0.213) of its own species. *Shorea* saplings entail no significant correlations with either seedlings or trees alone, but a weak correlation when combined in recruits (*r*=-0.229).

Abundance of *Schima* (Table 4.4) individuals in the various life stages are significantly positively correlated with individuals in all life stages of the same species. That is, plots with many *Schima* individuals in one life stage tend to have many individuals of the other life stages too. Plots with fewer individuals in a life stage tend to lack individuals of the other life stages as well.

Seedlings of *Shorea* correlate negatively with *Schima* seedlings, saplings and recruits while there is no correlation with trees. Saplings have an opposite trend – they do not correlate significantly with seedlings, saplings or trees but have a negative correlation with trees of *Schima*. *Shorea* recruits are negatively correlated with *Schima* in all life stages, while trees of *Shorea* have no significant relationships with *Schima* individuals. Seedlings of *Schima* correlate negatively with seedlings and recruits of *Shorea*. Saplings of *Schima* are negatively correlated with seedlings and recruits of *Shorea,* while no relationship is found with saplings or trees. *Schima* trees are negatively correlated with saplings and recruits of *Shorea*, while there is no relationship with seedlings or trees.

Land-use related explanatory variables

Canopy closure (Table 4.5) is the explanatory variable that covaries with all the other variables. An increase in canopy closure corresponds to an increase in litter, as expected. Canopy closure is negatively correlated with number of cut stems and degree of lopping, i.e. when more stems are cut or when lopping degree increases, canopy closure decrease, and vice versa. Number of cut stems and lopping degree show no relationship with litter cover, but there were a strong relationship between lopping degree and cut stems, as expected. It is reasonable that in plots that are highly disturbed there are more cut stems.

Table 4.5: Pearson two-tailed correlation coefficient (r) between land-use related explanatory variables. N = 90. **Bold face** denotes significant p-value, i.e. $p \leq 0.05$ for $r \geq 0.205$, $p \leq 0.01$ for $r \geq 0.267$.

	Canopy closure	Ground litter cover	Number of cut stems	Degree of lopping
Canopy closure	1	**0.378**	**-0.214**	**-0.290**
Ground litter cover		1	-0.023	-0.128
Number of cut stems			1	**0.553**
Degree of lopping				1

Co-variables

RRI has no significant associations with the other co-variables. Soil moisture and elevation are the only significantly correlated variables (*r*=-208, *p*=0.005).

Table 4.6: Pearson two-tailed correlation coefficient (*r*) between co-variables. N = 90. **Bold face** denotes significant *p*-value, i.e. $p \leq 0.05$ for $r \geq 0.205$, $p \leq 0.01$ for $r \geq 0.267$.

	RRI	Soil moisture	Elevation
RRI	1	0.151	-0.148
Soil moisture		1	**-0.208**
Elevation			1

Absence of strong associations between variables indicates that they can be used in multiple regressions as independent explanatory variables. None of the *r*-values found for the internal correlations (Table 4.5;Table 4.6) were collinear (*r*>0.8), thus they were sufficiently independent to be used in the same regression analysis.

4.1.3 Forest regeneration behaviour studied by forest size-structure and regenerative behaviour of seedlings and saplings

Regeneration behaviour of a forest is studied in terms of:

1. Population structure; forest density and size-class distribution derived from DBH-measurements, *and*

2. Seedlings and saplings number; mainly analysed as response to a set of variables that might impact their germination, establishment and early growth.

Forest density between the forests

The total number of seedlings, saplings and trees of *Shorea* and *Schima* in the sampled area is 12 391 individuals. Interpolated mean density per hectare is *c* 13 800. Number of individuals per sampled forest area (0.15 ha) is, on average, 2065. The percentage of individuals is very similar (15.2-15.9 %) in all forests except for Chisapani (21.9 %), which has *c* 6 % more individuals than the other forests. All stratification layers—canopy, sub-canopy and shrub layer—were present in all plots (not shown).

Table 4.7: Total counts per forest area of individuals of both species separately and combined and percentage of total individuals per forest area (species combined).

	Shorea robusta (all individuals)	*Schima wallichii* (all individuals)	Total record of individuals per 0.15 ha	% of total record per 0.15 ha
All forests	*11392*	*999*	*12391*	*100*
Mahalaxmi	1835	120	1955	15.8
Birienchok	1773	114	1887	15.2
Kuwadi	1773	203	1976	15.9
Taksartari	1808	141	1949	15.7
Chisapani	2585	129	2714	21.9
KP Bekhpari	1618	292	1910	15.4

Differences in mean DBH (species combined, Figure 4.9) between the forests was tested by a one-way ANOVA (F=3.378, p=0.005, df 5, sum of squares 1673.748). A post-hoc Tukey-test showed that Chisapani and KP Bekhpari were significantly different from each other (p=0.011) whereas the other forests did not differ significantly (p>0.05). The tests were repeated after removing the central trees from the analysis. This was done to see the effect central trees had on the succession history of the area. The ANOVA indicated that the forests were significantly different from each other in terms of DBH (F=8.410, p=<0.001, df 5, sum of squares 1514.122). The post-hoc Tukey-test suggested that Birienchok, Taksartari and Chisapani were significantly different from Mahalaxmi and KP Bekhpari (p<0.05), while Kuwadi was significantly different from Mahalaxmi only. This reflects what we observed in the field. Mahalaxmi and KP Bekhpari had younger tree stands than the other forests. Removing mature trees from the analysis gave a better picture of the present regeneration.

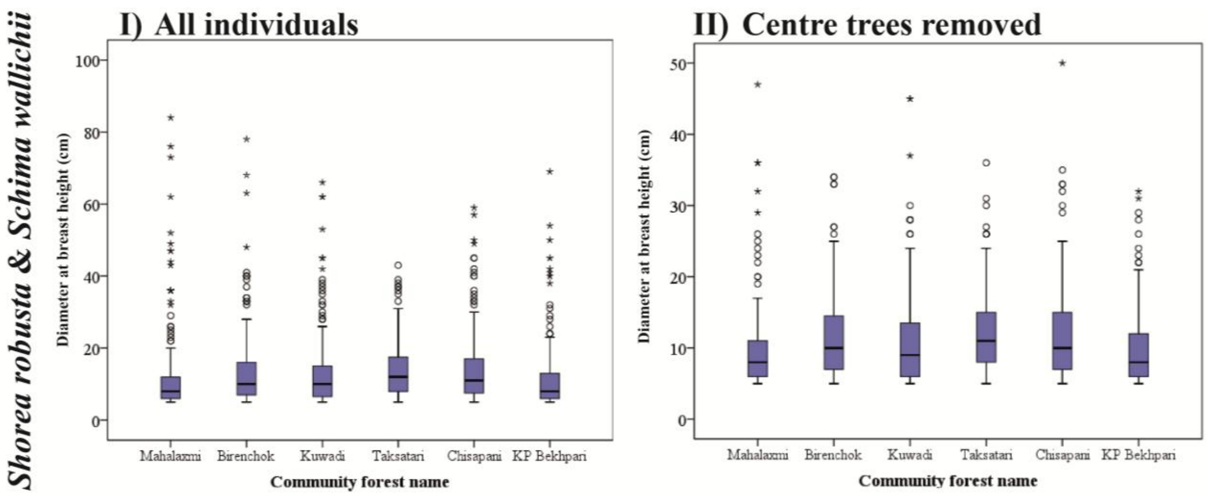


Figure 4.9: Median diameter breast height (DBH) distribution of *Shorea robusta* and *Schima wallichii* presented forest-wise with boxplots. Figure I) shows median DBH for all sampled trees. Figure II) portrays the DBH distribution when the central tree from each plot has been removed. Note different scales on the y-axis. See Figure 4.2 for boxplot characteristics.

Mean DBH between the species differs significantly ($t_{(1374)} = 4.021$, p =<0.001). *Shorea*'s mean DBH is 12.49 (±0.276) cm, while *Schima* trees are generally bigger, 16.55 (±1.089) cm.

Age-size relationship for *Shorea robusta*

Shorea's age can be estimated from DBH given its size class. Growth in the early stages of *Shorea* stands is fast (Gautam & Devoe 2006). According to Rautiainen's (1999 in Gautam & Devoe 2006) estimates of *Shorea* growth characteristics, a mean DBH of 9.5 cm equals a forest that is 9 years, and mean DBH of 13.9 cm equals a forest that is 13 years.

Tree diameter distribution

In general, the data show that the species have a viable structure (reverse J-shape) and a good fit to models (negative exponential and power function). The upper DBH size-class interval presented in the histograms is ≥45 cm which contains fewer than 2 % of the individuals. Note that the number of individuals differs greatly for the two species in the various forests: size-class histograms for *Shorea* forest-wise contain >150 individuals, while for *Schima*, only one forest has as many as 40 individuals, whereas the other forests have a mean of 13 individuals. The restricted abundance of *Schima* individuals forest-wise is too small to draw inferences from and focus is directed towards species overall regeneration.

Shorea robusta

The DBH size-class distribution for *Shorea* portrays a smooth, reversed J-shape distribution (Figure 4.10 I). Half of the adult trees were in the first cohort (5-10 cm), and the distribution declines continuously and monotonically with higher size-classes. *Shorea* distribution fits various models accurately (negative exponential function: (DBH classes 5-45cm) R^2=0.822; power function; R^2=0.950).

The different forests all have reversed J-shape size-class distributions (Figure 4.11 I) i.e. more young than old trees. Birienchok and Kuwadi reflect the continuous, monotonic declining pattern seen for the forests overall. KP Bekhpari and Mahalaxmi diverge from the other forests by having a higher frequency of young trees, few individuals with a DBH above 20 cm and an absence of trees in some size-classes. Taksartari and Chisapani have fewer trees than the other forests. Although the distribution declines with higher size-classes, the change in size is not consistent from one cohort to the next.

Schima wallichii

The DBH distribution of *Schima* trees also shows a reverse J-shape (Figure 4.10 II) and has a very accurate fit to the models it was tested against (negative exponential function (DBH-classes 5-45cm): R^2= 0.910; power function; R^2=0.880). There are trees in all size-classes: younger trees are more abundant than older trees though change in number from one size-class to the other does not monotonically decline, but is rather inconsistent. Trees in the first two cohorts (5-15 cm) make up *c* 60 % of all *Schima* trees. The following size-classes decline irregularly, leaving three classes with more individuals than the class it follows.

When *Schima* trees are portrayed forest-wise (Figure 4.11 II) the distributions are not so uniform. Kuwadi has a smooth and reverse J-shaped size-class distribution. It has significantly more individuals than all the other forests (F= 4.385, $P(F)$= 0.001). Birienchok, Taksartari and Chisapani also have size-class distributions that are reverse J-shaped, despite only having a few individuals. All forests except Chisapani have individuals in the smallest size-classes. Chisapani however lacks individuals in more than the first cohort and the distribution is uneven and generally consists of more mature trees than the other forests. In Birienchok and Taksartari a concentration of older trees (DBH 30-35 cm) was registered. Mahalaxmi and KP Bekhpari depart from the other forests by their very uneven size-class distributions. They lack individuals in several size-classes and they do not conform to the reverse J-shaped distribution.

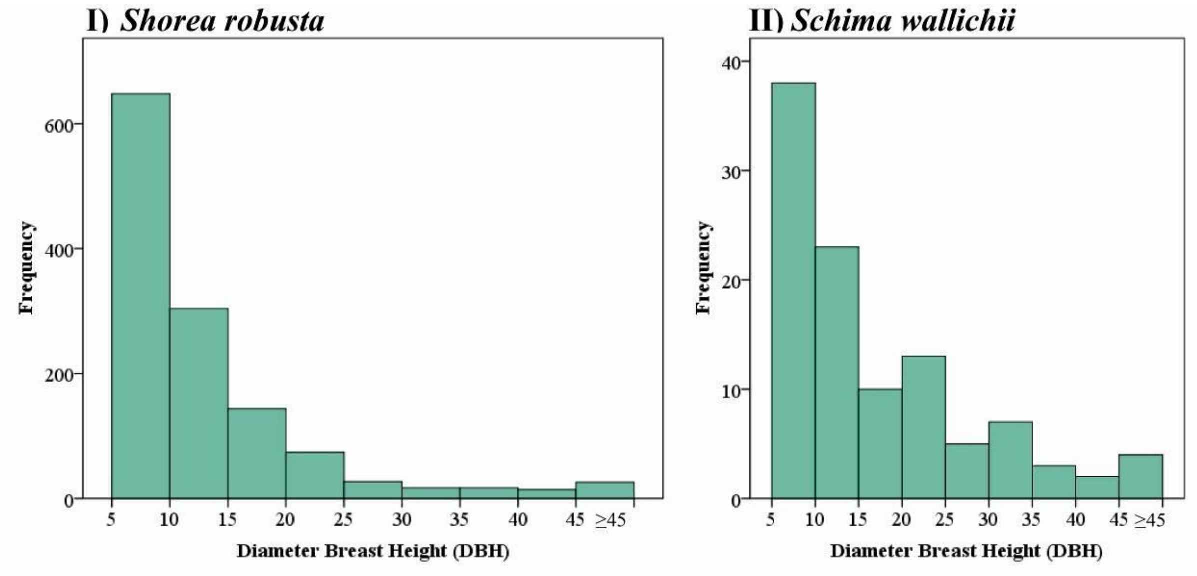


Figure 4.10: Size-class distributions for I) *Shorea robusta* and II) *Schima wallichii*. Size-classes are divided into DBH intervals of 5 cm up to 45 cm, with a final class of trees ≥ 45 cm.

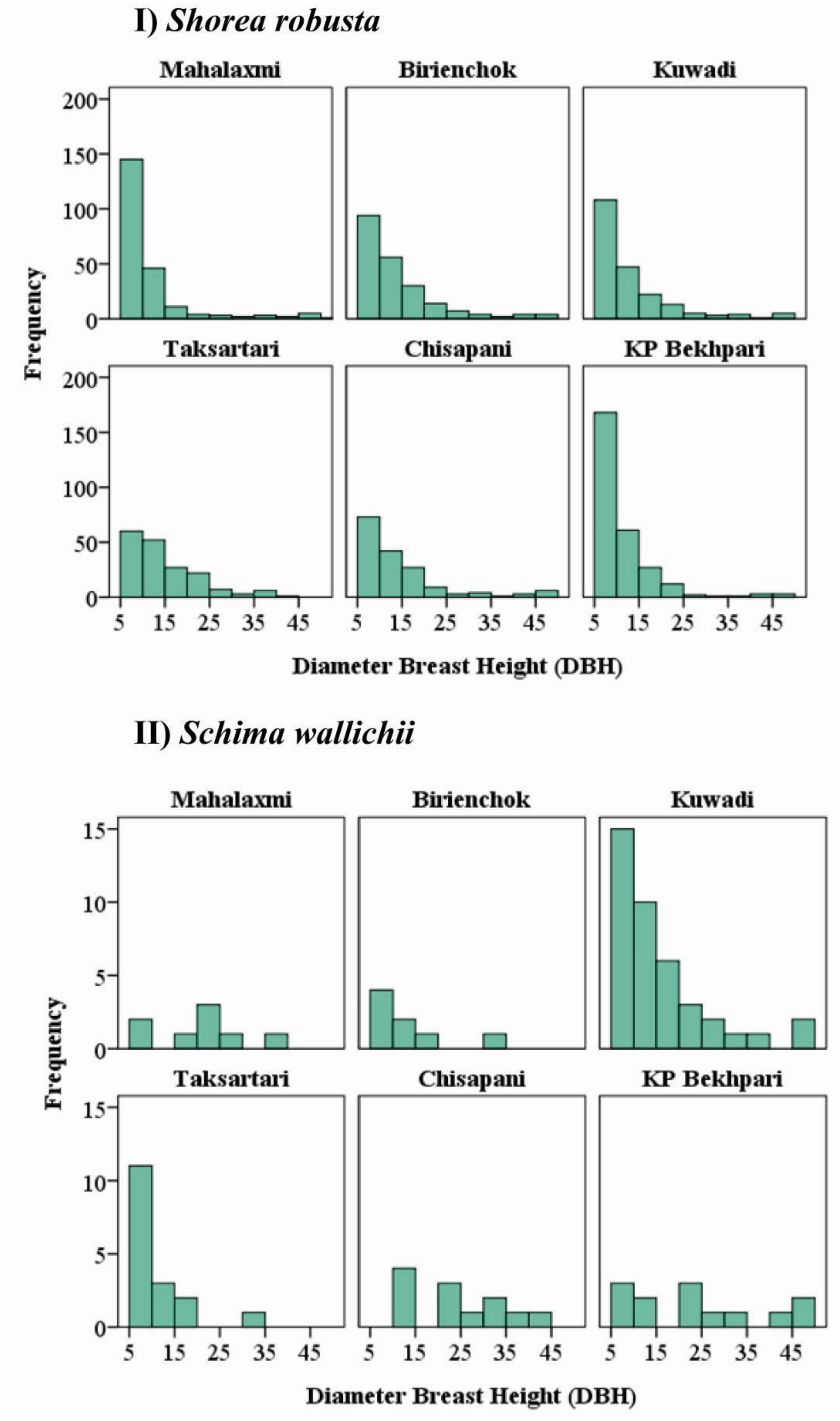


Figure 4.11: Forest-wise size-class distributions for *Shorea robusta* and *Schima wallichii* trees. Size-classes are divided into DBH intervals of 5 cm up to 45 cm, with a final class of trees ≥ 45 cm.

Distribution, regression, multiple regression and spatial autocorrelation of recruits

Shorea robusta

Shorea recruits were prevalent in more than 95 % of the plots. Seedlings were present in all of the plots, and the few plots with no saplings were restricted to two forests. Mean number of seedlings per plot was 94.22 (± 5.43) while saplings were 18.19 (±1.70) (Table 4.1 I).

Regression analyses (Table 4.8;Figure 4.13;Figure 4.12;Figure 4.14) showed that canopy closure impacts seedlings and saplings negatively, i.e. when canopy closure increases, the abundance of seedlings and saplings decrease (exponential fit: F=4.906, p=0.029; linear fit F=8.717, p=0.004). Canopy closure explains *c* 9 % of variance in saplings response, but only 5.3 % for seedlings. It should be noted that most of the sampled plots had a closure between 40 and 70 %, which may create a slight bias as the number of plots in each sampling interval is unequal. A variable with a significant impact on all life stages of *Shorea* was litter cover. Seedlings (linear fit: F=8.490, p=0.005), saplings (quadratic fit: F=4.340, p=0.016) and recruits (linear fit: F=9.816, p=0.002) decreased with increasing litter cover, while trees (linear fit: F=4.426, p=0.038) were more abundant when litter cover was higher. Litter cover explains *c* 9 % of the variance in seedling and sapling life stages, but only a small portion (4.8 %) for tree abundance. Whereas the impact of litter cover on seedlings is negative, saplings show a unimodal response, meaning that plots with an intermediate cover between 40-70 % favour plant establishment. Note that the most frequent litter cover was 40-70 %. This might create a slight bias, although the few observations point in the direction that recruits were fewer if the litter cover was either below or above this optimum range. Lopping and cut stems significantly impacted seedlings (p<0.05) but not saplings (p>0.05). More disturbed plots have fewer seedlings than less disturbed plots. Increase in degree of lopping decreases seedling numbers (linear fit: F=4.677, p=0.033), and the same is true for number of cut stems (linear fit: F=4.480, p=0.031).

Soil moisture did not have a significant impact on sapling abundance (p>0.05) whereas it showed a significant positive linear relationship with seedlings (F=8.115, p=0.005). Increasing soil moisture increases the abundance of seedlings, and explains 8.5 % of the variance within the response variable. RRI did not impact seedlings and saplings significantly (p>0.05).

When the abundance of seedlings and saplings is combined, results are strengthened as they reflect a greater sample. Canopy closure (F=9.416, p=0.003), litter cover (F=9.816, p=0.002), cut stems (*F*=4.133, *p*=0.045), RRI (*F*=4.547, *p*=0.038) and soil moisture (*F*=7.387, *p*=0.008) have significant 1st order relationships with recruit abundance. While canopy closure, litter cover and cut stems restrict abundance of recruits, increasing soil moisture and RRI-values favour establishment and development. The proportion of variance in the response explained by significant independent variables varies from 4.8 to 10 %.

Explanatory variables were modelled in a multiple regression (Table 4.9;Figure 4.14). The combined terms for *Shorea* increased the explained variance (R^2) to more than 20 % for seedlings, saplings, recruits and trees separately. The two variables that explained the most variance separately, namely ground litter cover and soil moisture, were used as predictors in the seedling regression. Cut stems, although the variable that explains the third most variance, was not significant. Instead, degree of lopping made a significant contribution to the model. The bivariate model explains 21.4 % of the variance and is highly significant P(*F*)=<0.001. Saplings were best predicted by canopy closure, litter cover and soil moisture which together accounted for 20 % of the variability in saplings. The trivariate model is highly significant P(*F*)=0.002. The multivariate model (Table 4.9) for recruits included three variables for explaining *Shorea* recruit's abundance (soil moisture, litter cover and RRI). This model explained nearly 30 % of the variance of the recruits. Soil moisture and ground litter cover, both important for seedlings and saplings, were the major explaining factors. The model was highly significant P(*F*)=<0.001. Regression residuals for the multiple models of *Shorea* were approximating standard normality, although some significant deviations were evident. Deviations reflect that there are some factors that are not included that may have explained a significant part of the variation in number of *Shorea* recruits and adults. This is particularly true at the adult stage.

Spatial autocorrelation of *Shorea* (Figure 4.15 I) showed that trees were significantly positive autocorrelated, particularly over short distances ≤4 km. This indicates that the most proximate plots are more similar to each other than expected by chance. The residuals from the bivariate model had many positive significant Moran's *I* values. Negative autocorrelation indicates that the distance class is more dissimilar than expected. Recruits of *Shorea* were significantly negative autocorrelated in one distance class. After multiple regressions (Table 4.9) the residuals were not autocorrelated. *Shorea* saplings were positively autocorrelated in the first and the last distance class. The residuals had significant Moran's *I* values after multiple regression. Multivariate model regression for *Shorea* seedlings removed positive autocorrelation for the residuals in two distance classes.

Schima wallichii

Schima recruits were present in 72 % of the plots. Plots without seedlings were few (8 %) and distributed among all of the forests. Saplings were present in 80 % of the plots, most of them in Taksartari, Chisapani and Mahalaxmi. Mean numbers per plot were 7 seedlings (±0.808) and 3 saplings (±0.341) (Table 4.1 II).

Recruits (Table 4.8;Figure 4.13) show the same trends as those exhibited by seedlings and saplings separately: both lopping (quadratic fit: F=8.175, p=<0.001) and soil moisture (linear fit: F=12.793, p=<0.001) increase seedling abundance significantly. The influence of lopping on recruits of *Schima* is the best sole explanatory variable, explaining a total of 15.8 %. Soil moisture explains 12.7 % of the variance within the response variable. Canopy closure, litter cover, cut stems and RRI do not explain abundance of *Schima* (p>0.05).

Schima recruits were obviously best explained by the significant variables: soil moisture and lopping (Table 4.9;Figure 4.14). The bivariate model explained 19 % (P(F)=<0.001) of the variance in the recruit variable. Regression residuals for the recruit's model of *Schima* were very close to standard normality, meaning that the model probably included the factors which are most important in explaining establishment and development of *Schima*.

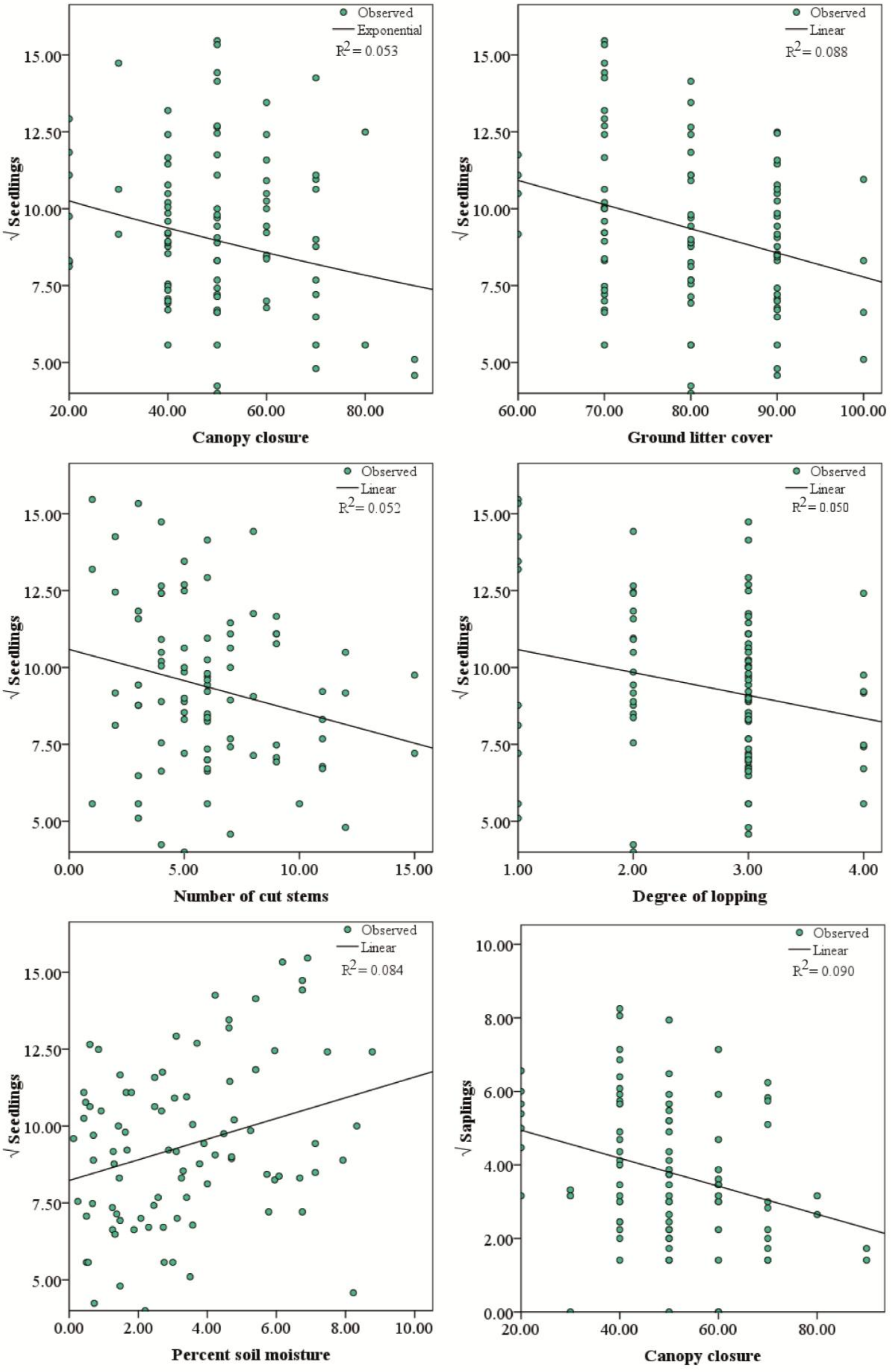
Recruits (Figure 4.15) were negatively autocorrelated in the 9th distance class: plots *c* 15 km apart from each other. After multiple regression (Table 4.9) the residuals did not show significant Moran's *I* values in the respective distance class. Negative autocorrelation was generated in the next distance class.

Regression analysis of explanatory variables associated with response variables

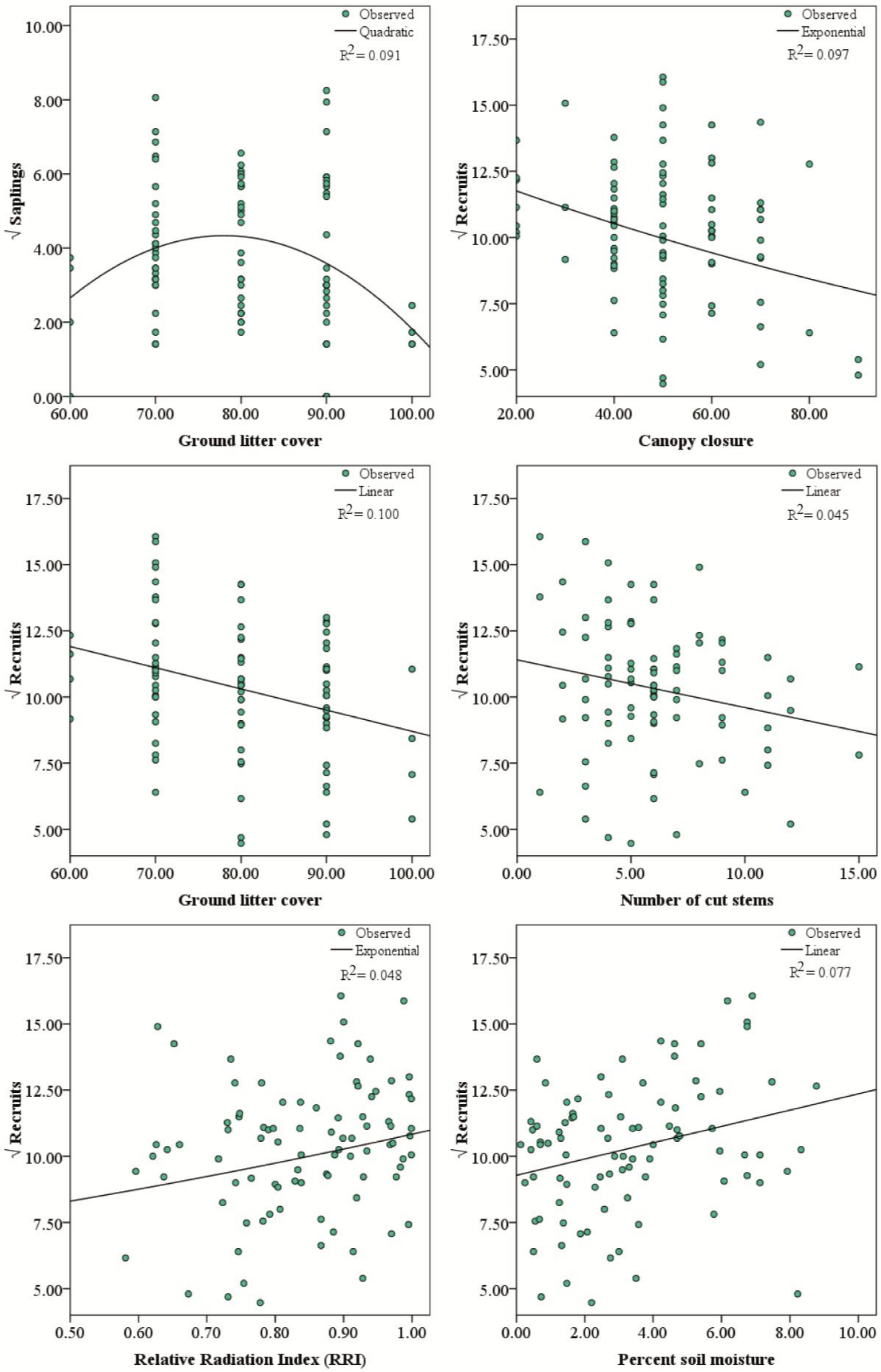
Table 4.8: 1st (linear and exponential), 2nd and 3rd order best-fit regression analyses of the impact of explanatory variables and co-variables on square-root transformed response variables. N=90. **Bold** face denotes significant model *P*(*F*) and term *p*(*t*) values (*P*/*p*≤0.05). * Note that lopping is an ordinal variable (Table 3.2), thus the assumptions of continuous variables are violated.

	Response	Explanatory variable	Order	df	*F*-value	*P*(*F*)	R^2	t-value	p(*t*)
√*Shorea robusta*	Seedlings								
		Canopy^2	1	88	4.906	**0.029**	0.053	-2.215	
		Litter	1	88	8.490	**0.005**	0.088	-2.914	
		Cut stems	1	88	4.840	**0.031**	0.052	-2.199	
		Lopping*	1	88	4.677	**0.033**	0.050	-2.163	
		RRI	1	88	2.468	0.120	0.027	1.571	
		Soil moisture	1	88	8.115	**0.005**	0.084	2.849	
	Saplings								
		Canopy	1	88	8.717	**0.004**	0.090	-2.952	
		Litter	1					2.679	**0.009**
		Litter^2	1					-2.754	**0.007**
		Model	2	87	4.340	**0.016**	0.091		
		Cut stems	1					1.189	0.238
		Cut stems^2	1					-1.053	0.295
		Model	2	87	0.762	0.470	0.017		
		Lopping*	1	88	0.166	0.684	0.002	-2.952	
		RRI	1	88	1.131	0.290	0.013	1.063	
		Soil moisture	1					1.636	0.105
		Soil moisture^2	1					-1.686	0.095
		Model	2	87	1.423	0.247	0.032		
	Recruits								
		Canopy^2	1	88	9.461	**0.003**	0.097	-3.076	
		Litter	1	88	9.816	**0.002**	0.100	-3.133	
		Cut stems	1	88	4.133	**0.045**	0.045	-2.033	
		Lopping*	1	88	3.496	0.065	0.038	-1.870	
		RRI^2	1	88	4.547	**0.038**	0.048	2.111	
		Soil moisture	1	88	7.387	**0.008**	0.077	2.718	
	Trees								
		Canopy	1	88	2.821	0.097	0.031	1.680	
		Litter	1	88	4.426	**0.038**	0.048	2.104	
		Cut stems	1					2.826	**0.005**
		Cut stems^2	1					-2.579	**0.012**
		Cut stems^3	1					2.537	**0.013**
		Model	3	86	5.901	**0.001**	0.171		
		Lopping*	1	88	3.028	0.085	0.033	1.740	
		RRI	1	88	0.147	0.702	0.002	0.384	
		Soil moisture^2	1	88	2.407	0.124	0.027	-1.551	
√*Schima wallichii*	Recruits								
		Canopy	1					2.300	**0.024**
		Canopy^2	1					-2.459	**0.016**
		Canopy^3	1					2.530	**0.013**
		Model	3	86	2.241	0.089	0.072		
		Litter	1	88	0.223	0.638	0.003	-0.472	
		Cut stems	1	88	1.151	0.286	0.013	1.073	
		Lopping*	1					-1.325	0.188
		Lopping^2*	1					-2.071	**0.041**
		Model	2	87	8.175	**<0.001**	0.158		
		Soil moisture	1	88	12.793	**<0.001**	0.127	-3.577	

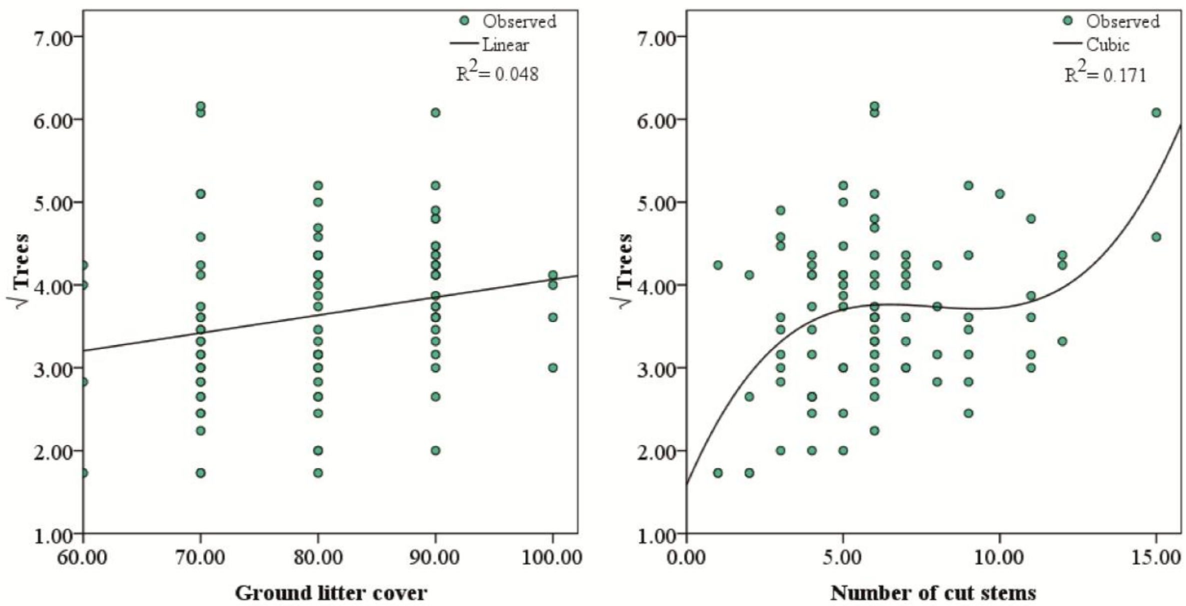
I) *Shorea robusta*



I) continuing *Shorea robusta*



I) continuing *Shorea robusta*



II) *Schima wallichii*

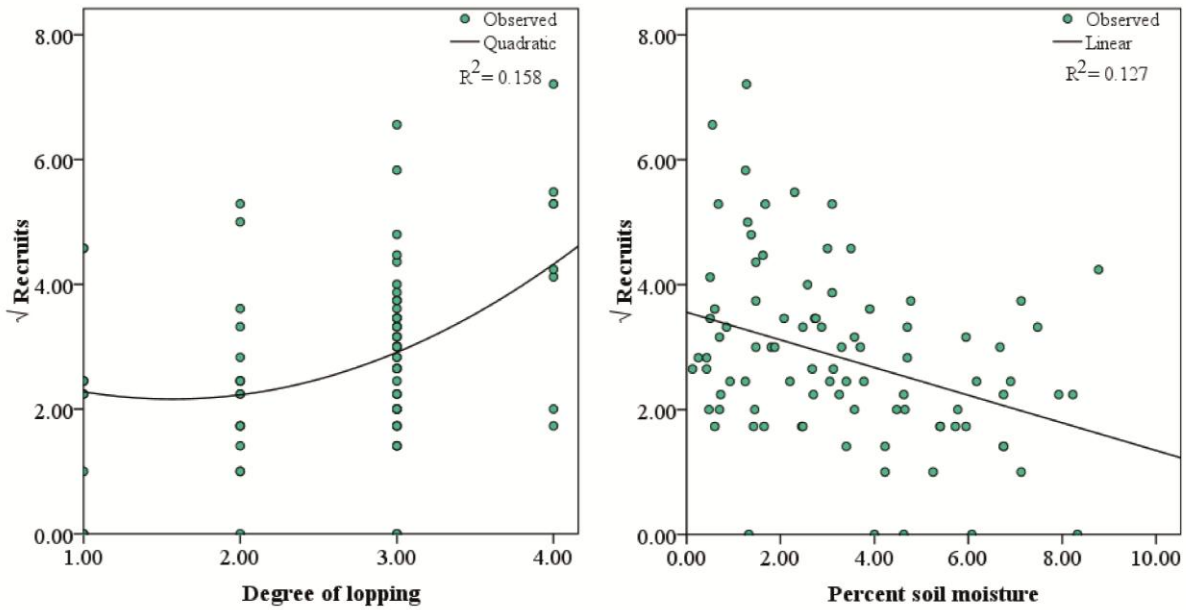
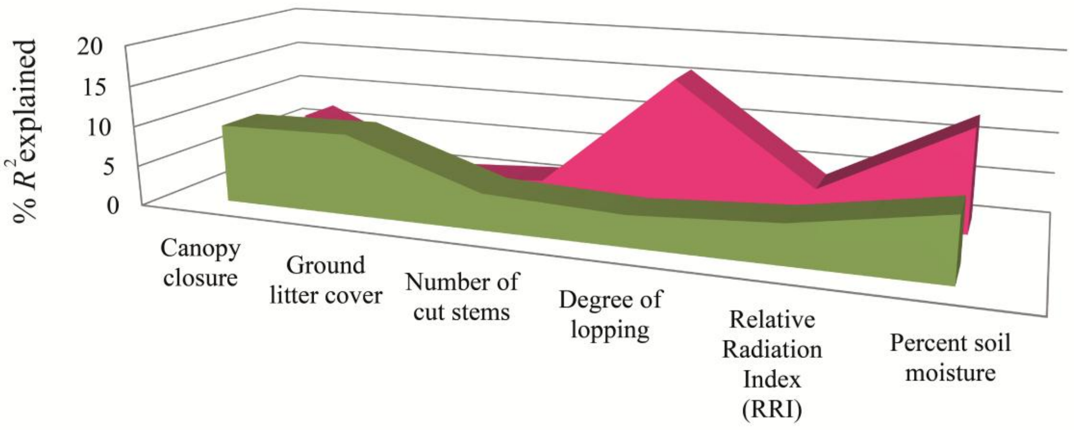


Figure 4.12: Linear (1st order) and curvilinear (quadratic 2nd and cubic 3rd order) regression analyses for significant ($p \leq 0.05$) associations (denoted with **bold face**) between explanatory variables and square-root transformed *Shorea robusta* seedlings, saplings and recruits; and square-root transformed *Schima wallichii* recruits. Order, *F*-values and *P*(*F*) that belong to the figures can be found in Table 4.8; Figure 4.13 and in the text.

Multiple explanatory variable regression for best fit of response model

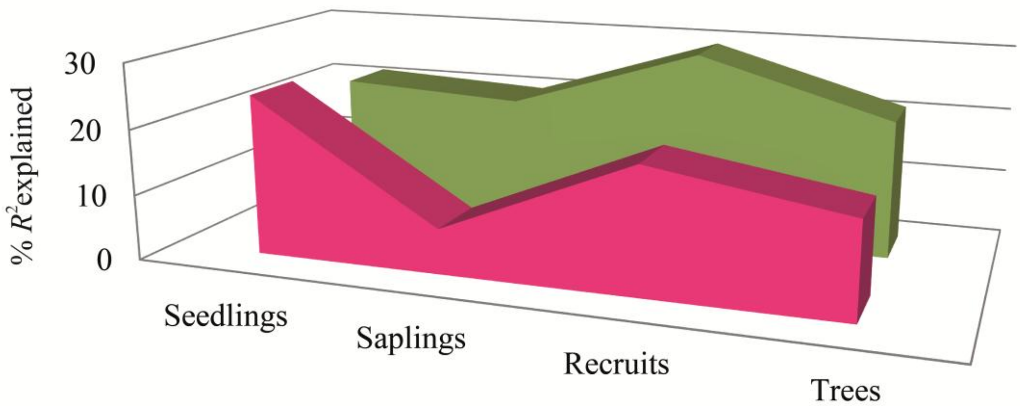
Table 4.9: Multiple regressions for best-fit model (denoted 'multiple regr model') by forward stepwise R^2 criteria *cf.* Austin (1990). N=90. **Bold face** denotes significant model $P(F)$ and term $p(t)$ values ($P/p \leq 0.05$). R^2 indicates the proportion of variance in the response variable explained by the model. * Note that lopping is an ordinal variable (Table 3.2), thus the assumptions of continuous variables are violated.

	Model	Explanatory variable	Order	df	*F*-value	*P*(*F*)	R^2	*t*-value	*p(t)*
√*Shorea robusta*	Seedlings								
		Litter	1					-3.419	**<0.001**
		Soil moisture	1					2.477	**0.015**
		Degree of lopping*	1					-1.996	**0.049**
		Multiple regr model	3	86	7.812	**<0.001**	0.214		
	Saplings								
		Canopy	1					-2.271	**0.026**
		Litter	1					2.928	**0.004**
		Litter^2	1					-2.942	**0.004**
		Soil moisture	1					2.207	**0.030**
		Soil moisture^2	1					-2.223	**0.030**
		Multiple regr model	5	84	4.201	**0.002**	0.200		
	Recruits								
		Soil moisture	1					0.924	**0.050**
		Soil moisture^2	1					0.257	**0.010**
		Soil moisture^3	1					0.020	**0.007**
		Litter	1					0.023	**<0.001**
		RRI	1					2.216	**0.032**
		Multiple regr model	5	84	6.952	**<0.001**	0.293		
	Trees								
		Cut stems	1					2.662	**0.009**
		Cut stems^2	1					-2.372	**0.020**
		Cut stems^3	1					2.342	**0.022**
		Litter	1					2.059	**0.043**
		Multiple regr model	4	85	5.653	**<0.001**	0.210		
√*Schima wallichii*	Recruits								
		Lopping^2*	1					2.638	**0.010**
		Soil moisture	1					-2.838	**0.006**
		Multiple regr model	2	87	10.308	**<0.001**	0.192		



% R^2explained	Canopy closure	Ground litter cover	Number of cut stems	Degree of lopping	Relative Radiation Index (RRI)	Percent soil moisture
Shorea robusta	9,7	10	4,5	3,8	4,8	7,7
Schima wallichii	7,2	0,3	1,3	15,8	3,7	12,7

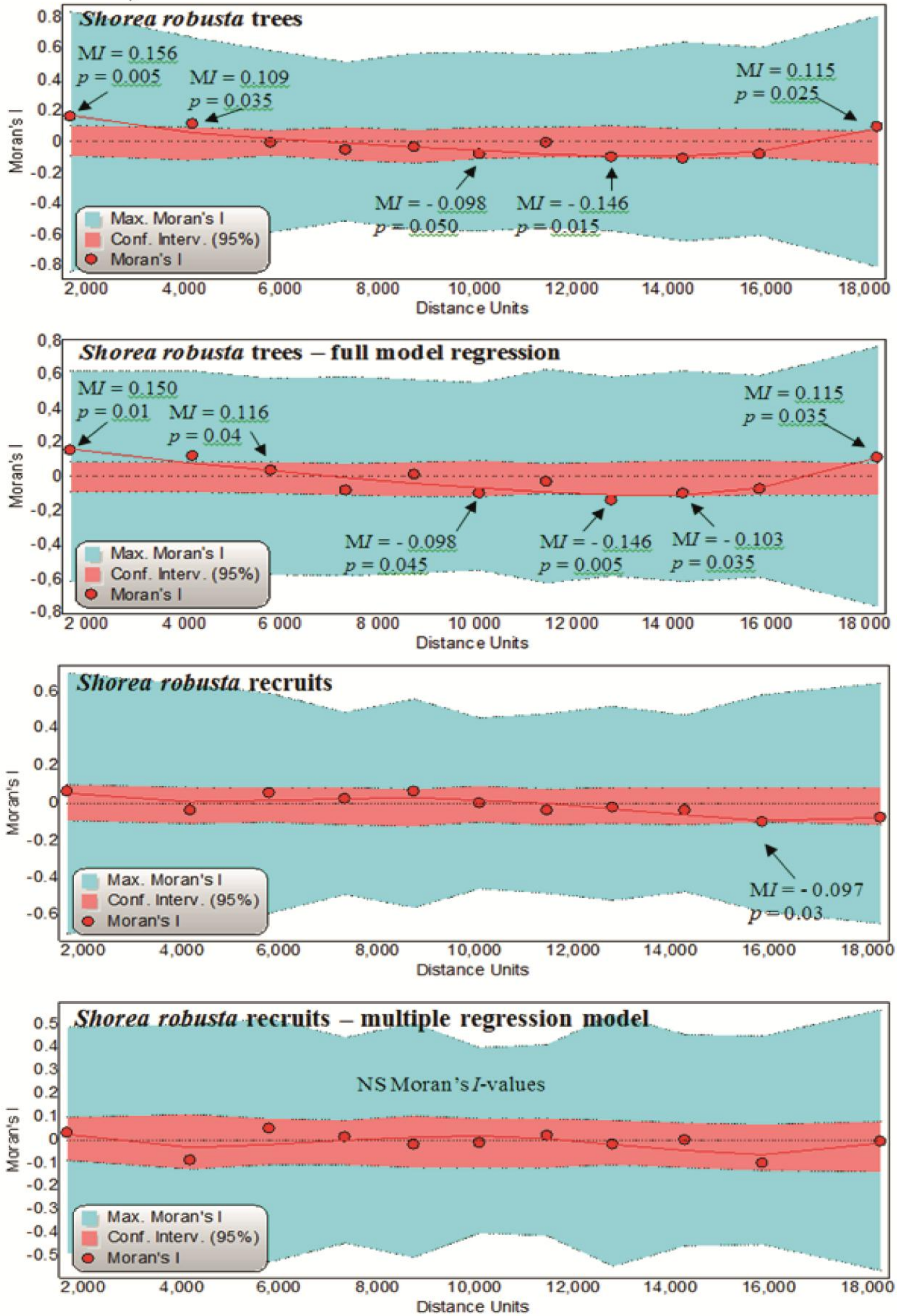
Figure 4.13: Percent variance explained (R^2) by explanatory variables regressed against species response variable (recruits). While canopy closure and ground litter cover are the disturbances that are most prominent in explaining variance in *Shorea robusta* recruits, lopping degree impacts *Schima wallichii* the most. Soil moisture alone explains a large part of the variance in both species.



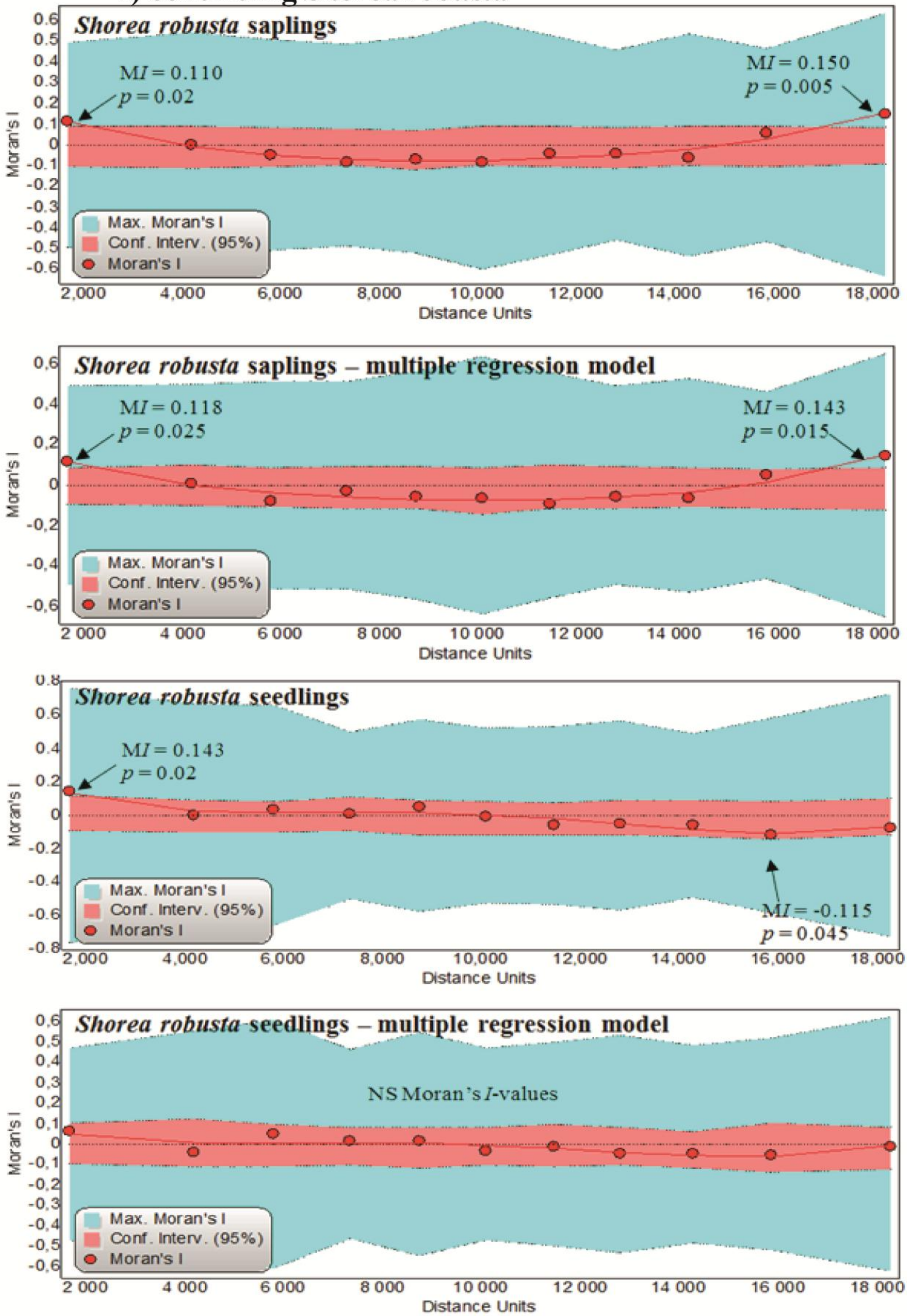
% R^2explained	Seedlings	Saplings	Recruits	Trees
Schima wallichii	24,6	6,9	19,2	14,5
Shorea robusta	21,4	20	29,3	21

Figure 4.14: Total variance explained (R^2) by multiple regressions for species life stages. Except for the seedling life stage, a larger proportion of the variance in *Shorea robusta* is explained compared to that of *Schima wallichii* (here shown for all life stages).

I) *Shorea robusta*



I) continuing *Shorea robusta*



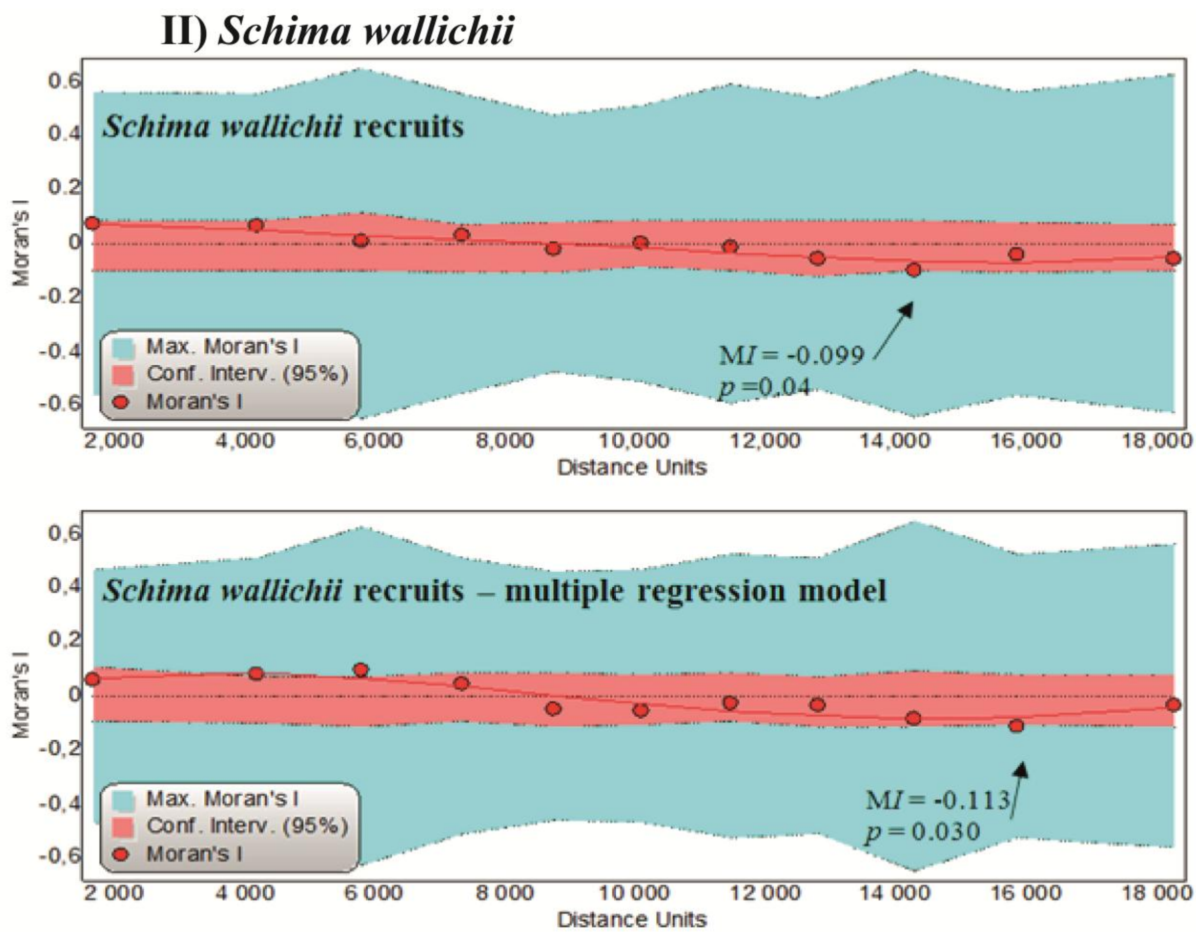


Figure 4.15: Moran's *I* of I)*Shorea robusta* for all life stages (trees, recruits, saplings, seedlings) and II)*Schima wallichii* recruits. First panel for each life stage portrays uncorrected response variables, and second panel the residuals of the multiple regression. NS = Non-significant.

4.1.4 Regeneration in relation to land-use, user-density and distance to the market

ANOVA and post-hoc Tukey tests (Table 4.10) outlined differences between the forests in terms of the abundance of recruits and differences in land-use related explanatory which might help explain regenerative differences in the response variables. Abundance of recruits was assessed as a response to land-use explanatory variables as well as to forest user-density and distance to Gorkha (Figure 4.16).

Forest regeneration in different CFs: abundance of recruits

Shorea robusta

The number of seedlings per plot differs significantly between the forests (F=7.989, p=<0.001). In Chisapani the abundance of seedlings is significantly greater compared to that of the other forests (p<0.05 for all forests). Mahalaxmi and KP Bekhpari have the fewest seedlings per plot, while Birienchok, Kuwadi and Taksartari have a medium number of seedlings per plot and do not differ significantly from each other.

Sapling number is significantly different between the forests (F=11.901, p=<0.001). A clear trend that is shown by the Tukey-test: Mahalaxmi and KP Bekhpari differ significantly from Birienchok, Kuwadi, Taksartari and Chisapani (p<0.05) which do not differ significantly (p=0.897) from each other in terms of sapling number.

Abundance of seedlings and saplings analysed separately was significantly different between the forests (p<0.05), and this was also true for recruits (p=0.005). Note that the number of recruits is highly affected by the high number of seedlings compared to that of saplings, meaning that Chisapani, the forest with the greatest number of seedlings differs significantly in recruits number (p<0.05) compared to the other forests except Mahalaxmi (p=0.071). Mahalaxmi, Birienchok, Kuwadi and Taksartari do not differ from each other (p=1.000) and KP Bekhpari is quite similar to these forests.

Schima wallichii

Recruits, although they have about the same mean number in Mahalaxmi, Birienchok, Taksartari and Chisapani (p>0.05) varied significantly between the forests (F=3.291, p=0.009). Kuwadi is not significantly different from any of the other forests (p>0.05), while KP Bekhpari diverge from Mahalaxmi, Birienchok, Taksartari and Chisapani (p<0.05).

Differences in land-use related explanatory variables between the forests

All the variables (Table 4.10) varied significantly between the forests ($p<0.05$) except cut stems ($F=1.247$, $p=0.295$). Canopy closure is significantly different ($F=2.591$, $p=0.031$) between the forests. It should be noted that a significant difference only exists between the closure in Mahalaxmi and Kuwadi ($p=0.020$), whereas differences between the other forests are insignificant ($p>0.05$). Litter cover ($F=8.005$, $p=<0.001$) has a clear twofold trend. Mahalaxmi, Birienchok and Kuwadi part from the other forests by their high litter cover percentage ($p<0.05$). The two groups, either with high or low cover are relatively similar within. Lopping degree is also statistically significant between the forests ($F=4.511$, $p=0.001$). Kuwadi diverges from all forests ($p<0.05$) but Taksartari ($p=0.222$) does not diverge from any of the forests ($p>0.05$).

Synthesis of forest regeneration controlled by explanatory land-use variables for *Shorea robusta* and *Schima wallichii* – H_0, H_1-$_3$.

There were no significant relationships between user-density and distance from Gorkha in the recruits for *Shorea or Schima* (Figure 4.16). The few differences between the forests in terms of regeneration could not falsify $H_{0,}$ while they implied that H_1, H_2 and H_3 should be rejected due to the lack of patterns directly attributed to the explanatory variables. The one variable with impact on regeneration was distance from the village to the plot. Longer distances increased the abundance of *Shorea* recruits significantly, whereas no pattern was evident for *Schima*.

In general, depicting species abundance as a response to the human-ecological gradients did not describe particular trends and patterns which could explain the differences in abundance of recruits between the various forests. On this basis H_0 was accepted.

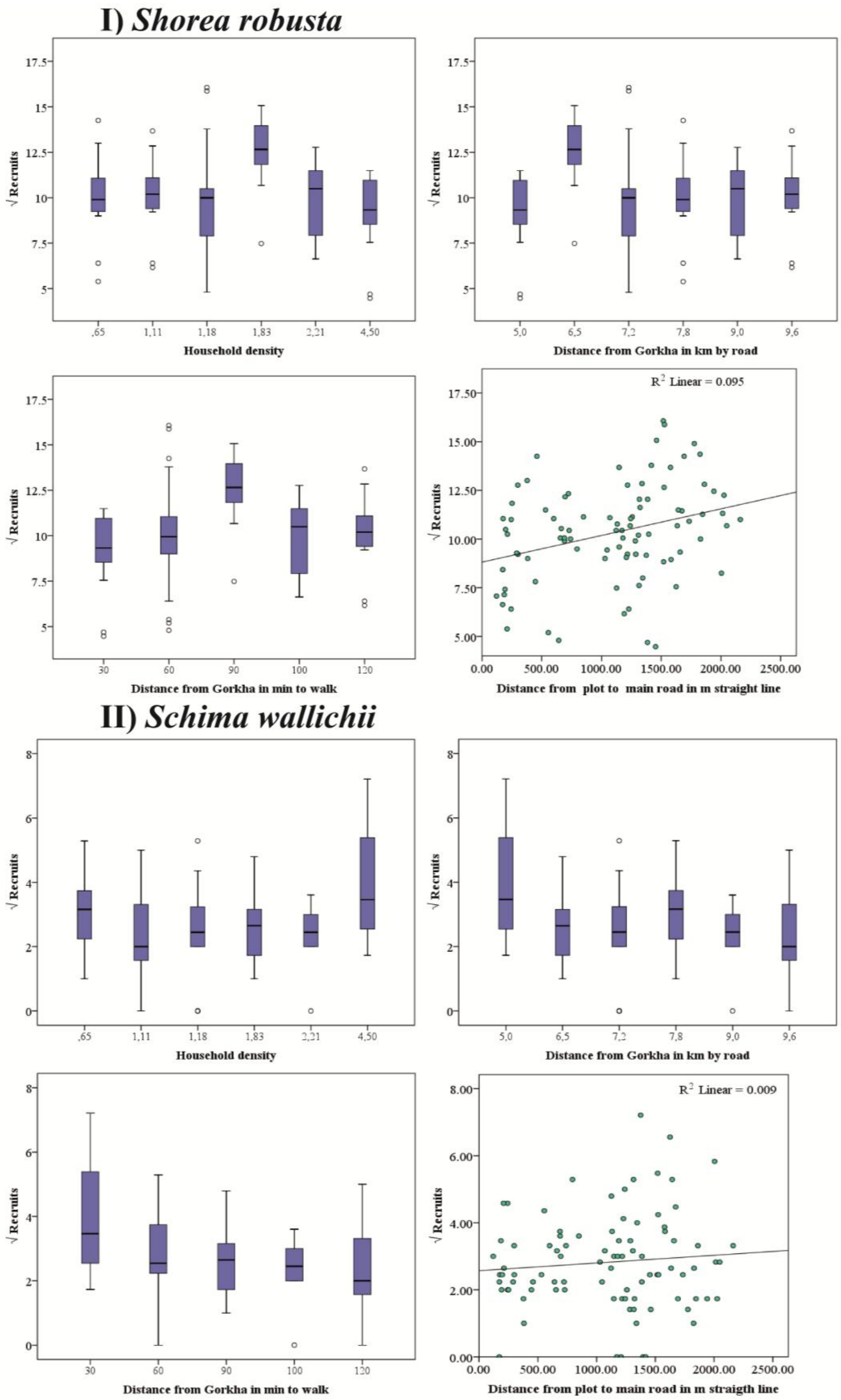


Figure 4.16: Boxplots and scatterplots of square-root transformed I)*Shorea robusta* and square-root transformed II)*Schima wallichii* abundance in relation to land-use related explanatory variables. Regression analyses (not shown) confirmed that land-use related explanatory variables and response variables were not significantly associated; $p>0.05$. Table 3.1: information on forests' explanatory variables. Figure 4.2: boxplot characteristics.

ANOVA and Tukey of forests in terms of explanatory and response variables

Table 4.10: One-way ANOVA and multiple comparisons Tukey-test of explanatory and square-root transformed response variables. The ANOVA analysis is performed between the forests; df =5. The Tukey test outlines significant differences between forests. All values in the Tukey test are *P*-values. **Bold** face denotes *P*(*F*)≤0.05.

ANOVA					√*Shorea robusta*			√*Schima wallichii*
	Canopy	Litter	Lopping	Cut stems	Seedlings	Saplings	Recruits	Recruits
Mean square	555.110	568.000	2.384	10.738	39.672	27.638	19.920	5.822
P(*F*)	**0.031**	**<0.001**	**0.001**	0.295	**<0.001**	**<0.001**	**0.005**	**0.009**
F	2.591	8.005	4.511	1.247	7.989	11.901	3.616	3.291
TUKEY								
Mahalaxmi								
Birienchok	0.666	0.987	1.000	1.000	0.663	**<0.001**	1.000	1.000
Kuwadi	**0.020**	1.000	**0.009**	0.392	0.866	**0.003**	1.000	0.733
Taksartari	0.425	**0.037**	0.808	1.000	0.859	**0.001**	1.000	1.000
Chisapani	0.989	**0.005**	0.974	0.989	**<0.001**	**<0.001**	0.071	1.000
KP Bekhpari	0.952	**0.020**	0.974	0.993	0.869	0.897	0.865	**0.022**
Birienchok								
Mahalaxmi	0.666	0.987	1.000	1.000	0.663	**<0.001**	1.000	1.000
Kuwadi	0.504	0.998	**0.009**	0.259	0.999	0.312	1.000	0.746
Taksartari	0.999	**0.005**	0.808	1.000	0.999	0.553	1.000	1.000
Chisapani	0.952	**0.001**	0.974	0.952	**0.017**	1.000	**0.040**	1.000
KP Bekhpari	0.989	**0.003**	0.974	0.965	0.101	**<0.001**	0.942	**0.023**
Kuwadi								
Mahalaxmi	**0.020**	1.000	**0.009**	0.392	0.866	**0.03**	1.000	0.733
Birienchok	0.504	0.998	**0.009**	0.259	0.999	0.312	1.000	0.746
Taksartari	0.742	**0.020**	0.222	0.392	1.000	0.999	1.000	0.772
Chisapani	0.103	**0.003**	**0.074**	0.781	**0.005**	0.397	**0.041**	0.886
KP Bekhpari	0.177	**0.010**	**0.001**	0.746	0.221	**0.071**	0.941	0.452
Taksartari								
Mahalaxmi	0.425	**0.037**	0.808	1.000	0.859	**0.001**	1.000	1.000
Birienchok	0.999	**0.005**	0.808	1.000	0.999	0.553	1.000	1.000
Kuwadi	0.742	**0.020**	0.222	0.392	1.000	0.999	1.000	0.722
Chisapani	0.811	0.987	0.996	0.989	**0.006**	0.651	**0.033**	1.000
KP Bekhpari	0.917	1.000	0.346	0.993	0.215	**0.025**	0.958	**0.026**
Chisapani								
Mahalaxmi	0.989	**0.005**	0.974	0.989	**<0.001**	**<0.001**	0.071	1.000
Birienchok	0.952	**0.001**	0.974	0.952	**0.017**	1.000	**0.040**	1.000
Kuwadi	0.103	**0.003**	**0.074**	0.781	**0.005**	0.397	**0.041**	0.886
Taksartari	0.811	0.987	0.996	0.989	**0.006**	0.651	**0.033**	1.000
KP Bekhpari	1.000	0.998	0.661	1.000	**<0.001**	**<0.001**	**0.002**	**0.050**
KP Bekhpari								
Mahalaxmi	0.952	**0.020**	0.974	0.993	0.869	0.897	0.865	**0.022**
Birienchok	0.989	**0.003**	0.974	0.965	0.101	**<0.001**	0.942	**0.023**
Kuwadi	0.177	**0.010**	**0.001**	0.746	0.221	**0.071**	0.941	0.452
Taksartari	0.917	1.000	0.346	0.993	0.215	**0.025**	0.958	**0.026**
Chisapani	1.000	0.998	0.661	1.000	**<0.001**	**<0.001**	**0.002**	**0.050**

4.2 Qualitative information

The information obtained from the CFUGs was structured forest-wise according to the different subjects that were explored (Appendix 1). In accordance to CF practices, rules and regulations, respondents were asked about forest health at the time when CF was implemented. The overall impression is that the CF management is quite similar between the forests. I will briefly outline the general findings and specify where exceptions and interesting cases in the CFs were outlined.

Forest status at hand-over time

The CFUG leaders independently of each other told the story of a degraded forest area at CF hand-over time. The forest health was described as poor, and forests consisted mainly of a few scattered and deformed trees. One informant used the word 'desert' to describe the forest area his CFUG got access to around 30 years ago. A few big trees remained in areas far from the road, downslope towards the river bottom. The heavy deforestation was attributed by the CFUG leaders primarily to the need for timber when Gorkha centre was expanding. The timber outtake was facilitated by the newly constructed road. The extension of Gorkha town was concurrent with uncontrolled forest regulation, described by CFUGs as practically 'open access' to forests resources. At CF implementation focus was directed towards protecting certain species. Most CFUG leaders reported that *Shorea* was protected either by rule, or in practice, whereas *Schima* was only protected in three forests. The current management focuses on protecting biodiversity.

Current forest management: forest-division, regulation and management activities

A general assembly is held once a year in all the CFs and the executive committee meet on monthly basis. The number of members in the executive committees and the structure is similar in all forests, and most households (>70 %) participate in the general assembly. In Mahalaxmi the CFUG leader estimated that all households were represented. To ensure that rules and practices decided upon by the CFUGs were obeyed by the forest-users, guards patrolled the forests during the dry season when *Shorea* is most heavily lopped due to leafing at this time. The 'guards' were mostly forest users themselves, either paid or working on a type of rotational basis. If rules were not obeyed, monetary fines were given. The CFUGs informed us that there were generally few cases in which users were fined, although it did happen that grazing restrictions and lopping/cutting regulations of *Shorea* and *Schima* were ignored.

The forests are divided into blocks and management carried out on a rotational basis. The different management activities and the rate at which they are carried out is described in the OP for each forest. According to these forest OPs, management shall be carried out in one block per year. All forests, except for Chisapani and KP Bekhpari reported that this structure was maintained. In these two forests management had been carried out, but not as regularly as described in the OP. Management included thinning, pruning and creating fire-breaks. While pruning and creating fire-breaks were carried out at approximately the same time and rate in all the forests, differences were evident in terms of thinning practices. Thinning, carried out during November to February, was conducted in one forest block per year and rotated annually in all forests but Chisapani and KP Bekhpari. In these two forests thinning had not been carried out over the last 5-6 years as it was perceived as disadvantageous for forest health.

Forest products and dependency

In all forests except Birienchok 100 % of the households were interested in timber (Figure 4.17). Regulations regarding timber outtake are given in the OPs and supported by instructions from the DFO. Households interested in timber had to apply to the CFUG for permission to cut, and priority was given either on a rotational basis or to those that were in most need. Practices on cutting and prices differed slightly between the forests.

The percentage of households interested in firewood varied more between the forests than for timber. Mahalaxmi reported that all households are interested in and collect firewood, while only about 20-30 % of the households in Birienchok have interest in firewood. Most households in Kuwadi and KP Bekhpari were highly interested in firewood. Most of the firewood is obtained through thinning activities when trees that are alive were allowed to be cut. Practices concerning dry wood collection were different. In some forests dry wood collection was restricted to certain times during the year, while it was allowed all year around in other forests.

Fodder collection was important, especially for people in Mahalaxmi and KP Bekhpari. In Birienchok and Chisapani fodder collection was restricted and CFUGs estimated that only around 30-35 % of the households had interest in fodder. Restrictions on fodder collection were slightly different from forest to forest. Green fodder could in general be cut as long as branches and areas sparse in seedlings and saplings were not disturbed. In some of the forests extra protection was given to *Shorea* and *Schima*, two of the most important fodder species. Chisapani and KP Bekhpari did not allow the cutting of seedlings or saplings. In Chisapani the CFUG leader remarked that most of the households relied on private land for collection of fodder.

Collection of leaf litter and ground grass was allowed, although not common. The expectation that ground litter cover would increase with increasing canopy closure held true. Instead of using leaves for mulching activities it seemed as if twigs and branches were more common.

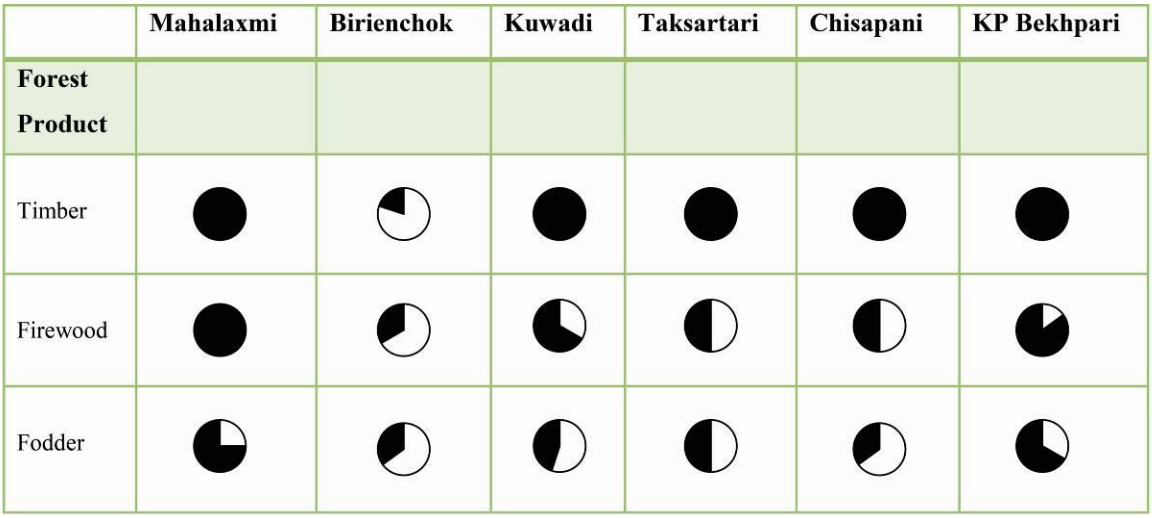


Figure 4.17: Estimates by CFUGs of household interest (%) in forest products sorted by CF. Black colour represents the % interested households.

Livestock and grazing

Livestock rates have decreased in all CFs over the last decades, and generally fewer households keep animals. Present rates of households per CF that keep livestock range from only 40 % in Kuwadi to 100 % in Mahalaxmi. The CFUGs explained decreases in households that keep livestock with increases in children's enrolment in schools and out-migration. As these two factors reduce the labour force this impacts herding and collection of fodder. Partly because of this the grazing pressure was limited and grazing more or less restricted in all forests, except in Birienchok. However, CFUGs noted that a few households had grazing animals, especially goats.

Fire and REDD$^+$-grants

The occurrence of forest fires with serious impacts was decreasing. This trend was explained by CFUG leaders as the effect of climate awareness rising through the REDD$^+$-program. The unfortunate effects of carbon emissions were well-known by most households and if fire was ignited it would soon be controlled. In Mahalaxmi, Birienchok, Kuwadi and Taksartari the last fire with massive impact was recorded about 4 years ago. No influential fires had hit Chisapani and KP Bekhpari in recent years. Grants from REDD$^+$-projects were used for fire prevention by means of making fire-breaks, awareness-rising work and improving cooking stoves in some CFs.

CHAPTER 5 DISCUSSION

5.1 Main findings

This study shows that, despite the prevailing disturbance from land-use related activities, *Shorea* and *Schima* regenerate sustainably under CF management. Both species were prone to disturbances from land-use related activities, but changing gradients of user-density and market proximity did not create a marked pattern in forest regeneration as hypothesised. This consequently means that H_0 was not falsified, whereas H_1-H_3 were rejected.

The contextualisation of the forest history showed a spatial and a temporal trend in deforestation and partly also in management implementation. The build-up of Gorkha and the construction of Abu Khaireni Highway were outlined as the two most prominent factors for explaining the distance pattern of deforestation, while the temporal aspect was captured with regard to time of management implementation, although this had not created a pattern in forest regeneration.

I will start by outlining what effects disturbance and co-variables have on forest regeneration, and thereafter make the connection to user-density, distance to Gorkha and the effects of CF management in regulating common-pool resources. I aim to show why Ostrom's rationale, captured in $H_{0,}$ was accepted despite that there were underlying heterogeneities in the forest user-density, the distance to Gorkha and the management practises. Comparatively better regeneration of recruits of *Shorea* and *Schima* in some forests than in others will be explained by forest management practices.

5.2 Regeneration of *Shorea robusta* and *Schima wallichii*

The studied CFs in Ludikhola are regenerating sustainably. *Shorea* dominates the forest stand-structure and it is the dominant species of the canopy layer. It is abundant compared to the sub-dominant *Schima* for all life stages (Figure 4.1), although both species seem to regenerate well. The finding that forests regenerate well in this area are supported by Lamichane's (2008) study from a sub-watershed within Ludikhola, which looked at changes in land-use and land cover by classifying and analysing Landsat satellite images from 1989 and 2002. The results show that throughout this period, forest cover increased by 0.94 % annually mostly at the expense of shrub- and bari-lands (upland dry agriculture which is rainfed). Lamichane (2008) associates these changes with CF, decreasing agricultural dependency, reduced number of livestock and less dependency on forests for energy. Despite the use of different methods these results are interesting due to the similarities of location and findings. Another comparable, nearby study of regeneration in the CF landscape of the Middle-Hills is Shrestha's (2005) study where one of the study sites is Namjung village in the Southern part of Gorkha district. The results show that density of *Shorea* was higher than other studies from Nepal had reported, and that the size-class distribution indicated sustainable forest management. Shrestha (2005) explains this by the full protection of *Shorea* and notes that this consequently reduced the regeneration potential of *Schima*. The non-sustainable size-structure of *Schima* was interpreted as the result of over-exploitation due to its priority as fuelwood species, which, together with its comparatively weaker coppicing ability compared to *Shorea*, reduced *Schima'*s regeneration potential so that there is a likelihood of developing mono-dominant *Shorea* forests. Shresta's (2005) results support that management practices can be important in explaining regeneration trends. This is shown by the hampered regeneration of *Schima*, analysed partly as an implication of the management restriction of *Shorea* outtake.

Size-class distributions portray regeneration of trees by their structure. Vetaas (2000b) argues that interpretations of forest regeneration may be better supported by size-class distributions than seedling counts because they represent longer time spans. This is especially true when seedling counts are short-term case studies where the measured environmental variables explain only small portions of the variability in the data, such as in my study. Condit et al. (1998), however, emphasise juvenile growth (saplings) as the strongest predictor of size-distribution. This is due to the finding that size-distributions entail only weak relationships with understorey species and no relationships with the growth rate of large individuals. Because size-distribution is highly influenced by a series of highly variable demographic variables, size-class distribution is not a good predictor of population dynamics alone (Condit et al. 1998). My study combines population structure with abundance of recruits in order to provide evidence and indications of both long-term and recent regeneration.

Population structure and abundance of recruits

The overall forest structure portrayed healthy forests with a smooth fit to the models against which they were tested. This was especially true for *Shorea*, as all the forests were sufficiently stocked with young trees although slight differences between them were evident (Figure 4.11). The forest structure in Birienchok is very smooth - *Shorea* trees decline regularly with DBH size-class. This might be explained by the relatively small interest users have in obtaining timber and firewood in this forest compared to the other forests (Figure 4.17). A similar logic can explain the healthy forest structure for both *Shorea* and *Schima* in Kuwadi, the least intensively used forest, only used by *c* 50 % of the households with access to the forest according to the CFUG. I relate the highly sustainable forest stand to the restricted product extraction, and I conclude that the use is balanced with regeneration. The average number of trees in Mahalaxmi is higher than overall forest average. The structure indicates that the regrowth is relatively recent, given that 70 % of all individuals are in the smallest size-class. When Mahalaxmi became a CF 19 years ago it was heavily degraded with only a few scattered trees left downslope. During the first ten years of management the forest user-density ($^{Hh}/_{Ha}$ = 2.03) was significantly higher than at present ($^{Hh}/_{Ha}$ = 1.11) (Table 3.1). Trees in the smallest size-class were probably established between 5-10 years ago (Gautam & Devoe 2006), meaning that *Shorea* increased concurrently with the decline in the intensity of use.

Apart from the rather smooth distribution of *Schima* in Kuwadi (Figure 4.11), the overall uneven structure reflects the limited number of individuals in most of the forests. Kuwadi and Taksartari are the only two forests with sufficient individuals to generate an informative size-structure pattern. Additionally, the mean DBH for *Schima* is biased due to the criterion of sampling around a mature tree. I therefore focus on the overall regeneration of *Schima* (Figure 4.10), analysed as sustainable by the greater abundance of younger than older trees.

Shorea is gregarious and regenerates intensively when establishment and growth conditions are favourable (Troup 1975b). This is reflected by the extensive regeneration of *Shorea* recruits in my study area, especially high in Chisapani while more restricted in KP Bekhpari and Taksartari.

5.2.1 Disturbance

Multiple variables were found to impact forest regeneration, some variables favoured it, others decreased it, and influences were found to be different at various life stages. Although no direct indications of unsustainable forest-use were found in this study, this alone was not taken as final proof of sustainability and regeneration. The results of regression analyses showed that both species, in their own specific way, were prone to land-use related disturbances, although these, *per se*, did not seem to exceed the carrying capacity of the forest. Direct and indirect disturbance factors influence forest regeneration in various ways. Sapkota (2009) found that disturbance, although the severity was not fully known, did explain parts of the evidenced differences in the stand structure, species composition and diversity of regeneration in Bhabar and Hill Sal forest.

The effects of anthropogenic disturbance on recruits are outlined for each particular species, and the disturbances which I will assess are actions in accordance with Grime's (1979) definition of disturbance as extraction of biomass. The effects of these disturbances vary and I will relate them to Singh's (1998) concepts of 'carrying capacity' and 'chronic' disturbance.

Lopping

Lopping has dubious effects on regeneration of the two species. There was significant negative correlation between *Shorea* and *Schima* for all size classes (Table 4.4). Decreasing numbers of *Shorea* were related to increasing intensity of lopping, and a logical suggestion from this is that increased lopping of *Shorea* facilitated establishment of *Schima*, which is less lopped. This relationship was strengthened by the significant increase in the abundance of *Schima* with more intensive lopping (Table 4.8;Figure 4.12). The increase of *Schima* recruits when *Shorea* decrease is probably related to characteristics of the latter species. *Shorea* can inhibit the establishment of other species because it regenerates in thickets that create shade which restrains the development of other species below it (Troup 1975b). Thus an area with fewer numbers of *Shorea* will likely have a reduced canopy and hence more light available at lower levels. From this it follows that the increase in *Schima* recruits is a possible response to improved light conditions. Despite this logic, I did not find any direct association between *Schima* recruits and density of the canopy closure or between number of *Shorea* trees and *Schima* recruits. Although I only have evidence for an association between *Schima* and lopping intensity, there is reason to believe that openings in the shrub and canopy layers by lopping of *Shorea* favours the establishment and growth of *Schima*.

Although lopping of *Shorea* seedlings was persistent and intensive, this 'chronic' disturbance did not seem to surpass its regeneration as it was abundant and gregarious throughout the studied forests. I relate this to *Shorea*'s ability to coppice well (Troup 1975b). The outtake of recruits may actually stimulate growth because a coppiced plant can produce many new sprouts (Figure 3.4). An exclusively negative outcome of lopping, e.g. that it may reduce seed production and tree vigour (Saxena & Singh 1984; Sagar & Singh 2004), is therefore unlikely to reflect the complex responses between and within species as lopping has been shown to have positive effects on regeneration of many species (Kumar Singh & Abbas 1994; De Cássia Guimarães Mesquita 2000 in Sapkota 2009). Molofsky and Augspurger (1992) argue that lopping may stimulate growth by increasing the availability of light to the forest floor and Vetaas (1997; 2000b) found that moderate lopping may increase species richness and facilitate regeneration rather than inhibiting it. Gautam (2001) shows that these findings also are reflected in *Shorea*'s response to lopping.

Forest-wise lopping intensity did not explain the distribution of *Schima* abundance because no forests were particularly more disturbed than the others in terms of lopping alone. *Schima* recruits were most abundant in KP Bekhpari where plots, on average, were similarly lopped to all other forests but Kuwadi where the plots were even less disturbed despite that this forest held second most *Schima* recruits. Increasing abundance of *Schima* with higher lopping intensity is however an expression of site-specific competition between the species: whereas forest-wise explanations for the relatively greater abundance of *Schima* recruits in some forests is maybe better understood and explained by differences in forest management practices. The banning of lopping and thinning in KP Bekhpari is a possible explanation factor for *Schima*'s favourable development in this forest. It should be noted that despite that these activities were banned, users collecting fodder were observed (Figure 3.7). However, the frequency and the intensity of the lopping activity seemed restricted and probably it did not overturn the system. The same pattern was detected for *Shorea* in Chisapani: where the highest abundance of recruits was found, lopping and thinning were management activities that had not been carried out during the last six years.

Cut stems

Number of cut stems is, together with lopping, a direct expression of disturbance, and these two variables were positively correlated. While fodder was mainly extracted from *Shorea* plants, both *Shorea* and *Schima* trees were cut for timber purposes (Troup 1975b; a; Storrs & Storrs 1990). Number of cut stems did not impact the abundance of *Schima* recruits, but decreased the abundance of *Shorea* recruits. This might be explained in several ways. First, plots where many stems are cut were likely to be more intensively lopped. This means that the disturbance is high, a factor that could have restricted regeneration of *Shorea* over that of *Schima* as it is the dominant species. Second, a reduced number of trees means less production of seeds, a factor that obviously restricts recruitment. On the opposite side, more cut stems may enhance the light at the ground by reducing the canopy cover: a factor that might favour seedling establishment. This was confirmed for *Shorea*, although not for *Schima*.

Canopy closure

Canopy closure is determined by lopping intensity which changes the structure and growth form of a tree. The natural crown of *Shorea* and *Schima* (Figure 2.11) trees is spherical (Orwa et al. 2009a; Orwa et al. 2009b), but intensive lopping will reduce the crown size, a situation that in turn decreases the shade cast by the tree (Figure 3.4). I expected the canopy closure to be higher where there were many trees. However, no significant correlation between these variables was found ($p>0.05$), meaning this expectation was not true for the prevailing forests. This might be related to the intensity of lopping, a factor which affects the natural growth of plants. Although the influence of lopping varies from one species to another, effects on species growth, yield and size-distribution are common (Meilby & Puri 2007). Lopping may thus disturb the natural self-thinning of a forest so that it thwarts the general -3/2 power law of self-thinning described by Weller (1987). Meilby and Puri (2007) found that height and crown width of certain fodder species (not *Shorea*) in Chitwan, Terai were negatively associated with lopping intensity, meaning that more intensive lopping reduced these factors. Gautam (2001), on the other hand, found that a one-event of lopping up to 80 % did not affect *Shorea*'s DBH, height, basal area or volume growth, and that moderate lopping (40 – 60 %) actually increased growth in forests that were young and dense. No associations between canopy closure and the number of trees, or between lopping intensity and the number of trees were found. However, a significant association was noted between lopping intensity and canopy closure, indicating that the canopy closure decreased where the lopping intensity increased. Based on the prevailing data I can not conclude what effects lopping had on *Shorea* and *Schima*'s growth, yield and size-distribution, and the mentioned associations are therefore only indicators of effects.

Shorea, especially in seedling life stage, is light demanding (Troup 1975b) and higher canopy closure reduced *Shorea* recruits significantly. *Schima* recruits were not impacted by changing canopy closure. This may reflect *Schima*'s modest light demand and the ability of its seedlings to tolerate shade during establishment (Troup 1975a).

Leaf litter

Although seasonal, *Shorea* leaf fall peaks in late winter/early spring from the middle of February to the middle of May (Troup 1975b). This means that the litter cover, consisting mainly of *Shorea* leaves, was at its peak during the time of sampling. The cover was extensive, a factor which may inhibit establishment of other species (Troup 1975b), but no statistically significant relations on the effect of litter cover on *Schima*'s regeneration were found. The total number of the littering species itself decreased significantly with increasing litter cover. It should be noted that litter estimation was crude, and that seasonal variability impacts the results, introducing a bias to this variable and rendering it unreliable. I might therefore be that increasing canopy closure (assumed to render more leaf litter on the ground) is more important variable than leaf litter in explaining the decrease in *Shorea*. This hypothesis is supported by the highly significant correlation between canopy and leaf litter (Table 4.5).

Fire

While fire easily eliminates seedlings and saplings, trees usually withstand disturbances from fire (Gautam & Devoe 2006). Shrestha (2005) and Tachibana and Adhikari (2009) report that fire occurrence in the Middle Hills has decreased lately, and the latter argue fire reduction is the main contribution of CF management in explaining improved forest conditions. According to CFUGs, fires in Ludikhola have become very rare and occur only occasionally. This was explained as the result of an increased focus on the negative environmental consequences of burning through the $REDD^+$ programme, through which CFs are paid to reduce emissions of carbon to the atmosphere (ICIMOD et al. 2010). The last fire with massive impacts in KP Bekhpari occurred seven years ago. Mahalaxmi, Birienchok and Taksartari reported a massive fire four years ago. This fire also impacted Kuwadi, although its impact was described only as "noticeable", not massive.

Obtaining fire data was not a prime focus of this investigation and the obtained qualitative data obtained were crude. Thus, I use them only as indicators and supporting factors in explaining the regenerative trends. According to Gautam and Devoe (2006) fire is one of the prime factors that affect the growth of *Shorea*. It is interesting to note that the CFUG in Chisapani, the forest with the greatest abundance of *Shorea* seedlings, reported that there had been no recent fires. Together with the restriction on lopping and thinning this might explain the high abundance of *Shorea* recruits. The CFUGs of the two forests with the greatest abundance of *Schima* report that fire has had little impact in recent years. As the current tree structure in KP Bekhpari is relatively young and probably reflects regeneration during the last 5-10 years: I speculate that the last massive fire in KP Bekhpari killed most recruits.

5.2.2 Co-variables

Elevation

An important factor in explaining *Schima*'s distribution may be elevation. Plots in KP Bekhpari were situated at elevations *c* 100 m above the other forests (Figure 3.2) and a slight change in species composition, such as more *Schima* and some occurrence of *Castanopsis indica* was evident. According to regression analysis (not shown) elevation was the most important variable in explaining the extensive distribution of *Schima* recruits. It should be noted that this regression analysis is highly biased by the fact that KP Bekhpari, which holds most *Schima*, is the only forest at an elevation around 100 m above the other forests. Field evidences support that elevation is influential for *Schima* regeneration and the sample elevation shift is just at *Schima*'s lower elevation boundary (Figure 2.7). The abundance of *Shorea* was not related to elevation.

Soil moisture and RRI

Schima preferred low, rather than high soil moisture. Its abundance decreased significantly when the moisture was above 4% (Table 4.8;Figure 4.12). Two forests, one of them KP Bekhpari, diverge slightly from the other forests by being less moist. The average moisture in KP Bekhpari is 2 % and this may in turn be part of the explanation for the high abundance of *Schima* recruits there. The average soil moisture in Kuwadi, which holds 40 % of all *Schima* trees, is however the highest among all the forests, exceeding 4 %. Soil moisture consequently fails to explain the many individuals of trees in Kuwadi. Restricted soil moisture therefore seems more important for the establishment and the early development of *Schima* than for tree growth. *Shorea* recruits on the other hand preferred it when the soil moisture increased, which supports Orwa et al.'s (2009b) finding that *Shorea* prefer well-drained moist sandy loam. Seedling establishment of *Shorea* was also favoured by increasing RRI, the expression of increased solar radiation.

Multiple regression

The multiple regression models increased the explained variability in the response variables. The included variables in the models were the same variables as those which explained most variability in the regression analyses alone, indicating that variables were not confounded due to colinearity. The most reliable models for *Shorea* are those for seedlings and recruits (*cf.* autocorrelation). The model for seedlings confirm that litter cover, soil moisture and degree of lopping all contributed to explain a unique part of the variance. Although it only explained *c* 20 % of the variation within seedlings, it shows that the human use has a local effect on regeneration. The effects seems however to be independent of the user-density and the distance to Gorkha (Figure 4.16). For the recruits, also reliable in terms of autocorrelation, the model explained *c* 30 % of the variability in the variable. Instead of lopping which was not significant for saplings and therefore not represented in the recruits category, RRI was taken in as the last significant variable. The same pattern was evident for *Schima* recruits. The multiple regression model, which included degree of lopping and soil moisture, was very close to normality and almost not autocorrelated. This means the land-use regime have impacted on the regeneration, although independently of the hypothesis variables.

Spatial autocorrelation

Autocorrelations were found in the distribution data of both species. Positive autocorrelation over short distances for *Shorea* indicate that plots close to each other were more similar than expected, which may be caused by the fact that nearby plots are likely to have similarities in underlying environmental conditions (biological- or human influences), and/ or dispersal from nearby neighbour trees, i.e. contagious biotic processes. The residuals from the multiple regression models for recruits and seedlings did not have significant autocorrelation, and this strengthen the interpretation of these models. In contrast, the residuals from the multiple regressions model for saplings and trees still had significant autocorrelation, and the interpretation of these results will be less reliable. *Schima* recruits were slightly negative autocorrelated in one of the most distant distance units, i.e. plots far from each other were more dissimilar than expected. I interpret this as reflecting that KP Bekhpari, the forest farthest away from the other forests, was quite different in species composition. The spatial structure in the residuals was removed for the recruits when lopping and soil moisture was included in the model. This implies that these factors, in addition to elevation, are important in explaining the difference in *Schima*'s distribution.

In summary, the regeneration of the two species was quite differently impacted by the environmental variables (Figure 5.1). *Shorea* was more heavily impacted by various disturbances than *Schima*, whose abundance was positively impacted by increased lopping of *Shorea*. The fact that *Schima* showed little response to these disturbance factors might reflect that these factors do not influence its development significantly, or that the rather limited sample size of *Schima* compared to that of *Shorea* fails to capture the effects of disturbance other than the positive effect of increased lopping of its competitor. *Schima* is less preferred for non-timber forest products (NTFP) than *Shorea*, which may explain why ground litter cover and canopy closure do not have significant impacts on its abundance.

5.3 The influence of human-ecological factors on forest regeneration

Forest-population dynamics; the influence of user-density on forest regeneration

Population growth has been portrayed as one of the most important factors in explaining forest degradation in Nepal (see e.g. Eckholm 1975). Based on the strong link between these two factors in the literature, I hypothesised that forest regeneration was likely to be influenced negatively when user-density, and hence forest-product outtake, increased. However, no discernible patterns between user-density and forest regeneration of either species (Figure 4.17;Figure 5.1) were found in the current study.

The findings from this study are in line with Varughese's (2000) study of population and forest dynamics in the Middle Hills. This study found no significant associations between forest condition and population growth, whereas strong associations between local collective action and improved forest conditions were evident .Varughese therefore challenges the presumption that factors related to population growth are the primary factors causing forest degradation. Two of the studied forests are connected to Gorkha and the market there. While forest conditions in one of the forests were improving, forest health in the other was worsening. Varughese (2000) explains these differences by the present institutional arrangements, because they are influential in determining how users cope with changes in the resource condition. Improving forest conditions were found when institutional arrangements were present, and when genuine users had high collective action between them: while forest conditions were worsening in lack of such.

Another interesting study that contrasts the apparent link between population growth and deforestation was undertaken in Bhogteni, about an hour's walk from Gorkha. Fox (1993) found that the forest condition had improved from 1980 to 1990, despite an annual population growth of 2.46 % and almost constant livestock numbers and fuelwood collection rates. Fox thereby (1993) contrasts the neo-Malthusian view that population growth beyond dispute leads to degradation, but has no clear evidence that population growth would lead to internal innovations in which people pushed the establishment of forest management systems as hypothesised by Boserup (1965) either. Instead he indicates that Brookfield's (1984 in Fox 1993) argument: that population growth and perceived environmental risk can trigger the development of more sustainable management systems might be explicable in the case of Bhogteni. Together with population growth, changes in the agrarian system were, by Fox (1993), analysed as factors which played major roles in user's willingness to seek more efficient forest management methods. Fox (1993) concludes that the population growth and the high population density did not lead to forest degradation in Bhogteni, and he indicates in line with Gilmour (1991 in Fox 1993) that despite population growth in the Middle Hills of Nepal, sustainable management systems are developing progressively.

Neither Varughese (2000) nor Fox (1993) found significant associations between population growth and forest condition. They conclude that the management system together with changes in the agrarian system is more important than the actual population density in explaining the condition of the forest. This might be the case in Ludikhola, a thread I will pick up in sub-chapter 5.4 “The success of CF management in regulating common-pool resources: implications of CF management in terms of forest sustainability”. Alternatively, it is a possibility that user-density matters in terms of forest regeneration, but this study failed to spot a systematic pattern in the response of recruits in Ludikhola, even if such existed.

Several factors may explain why user-density did not influence the number of recruits. Socioeconomic differences and especially wealth is argued to be one of the prime factors in determining differences in the forest-product outtake (Adhikari et al. 2004b). CFs provide more products to local households than the two other types of organization studied by Adhikari et al. (2004b). Collection of forest products in the Middle Hills has increased since CF establishment (Adhikari et al. 2007). Household dependency on forest products is strongly connected to the economic status of local forest users, in which products are more important for poorer than richer households. This is also true for fuelwood collection which varies greatly between rich and poor (Sapkota & Oden 2008). Poor households are more dependent on forest resources than rich households. This is illustrated by the fact that poor households collect ten times more fuelwood than rich households from the CFs. If a household’s socio-economic status reflects fuelwood extraction, then user-density, calculated as households per hectare, is ineffective because forest-product extraction depends more on socioeconomic status than on population density under CF management. Future research should test if there is a relationship between forest regeneration and the socio-economic statuses of the CFUGs in the Ludikhola forests. Another factor that was not considered in my study was out-migration. It might, in the same manner as socioeconomic status, bias the user-density variable and the resource pressure as the actual forest users might be fewer than indicated by the household ratio. Out-migration is an important factor of population decline in the Middle Hills (Sapkota & Oden 2008). This is also the case for Gorkha where more than 30 % of the households in 2011 reported that a minimum of one household member (average household size 4.08 persons) was absent or living outside the country (CBS 2012). I noted from conversations with CFUGs and forest users that young men migrated from Gorkha to surrounding areas or Gulf countries to seek job opportunities there. The extent of the migration was not quantified and hence it cannot be used for purposes other than illumination of a possible source of error. Despite that wealth and migration were not evaluated, I believe that household density did not show a systematic pattern in regeneration that was overlooked. Based on this H_1 was rejected.

Forest-distance dynamics: the influence of distance on forest regeneration

Distance was used as an indirect measure of access to a resource, and I hypothesised that users in forests that could easily access the market in Gorkha were less dependent on CF product-extraction than those who had to travel longer to access an alternative extraction site. It follows from this that I assumed these forests would be less intensively used. Distance to Gorkha in km by road or walking time did not create a pattern in the regenerative response which means I found no evidence that households that are farther away from the market depend more on forests and therefore uses CF resources more heavily than those CFs that were closer to Gorkha (Figure 5.1). Longer distances to the plot from the main road created a pattern in regeneration and significantly increased the number of *Shorea* recruits.

Construction of a road in a mountain area is a key factor in changing the landscape (Allan 1986). It enables easier to access to markets, and seasonal migration, cash labour and diffusion of food plants to and from the newly connected areas. The development of Gorkha and the concurrent construction of the Abu Khaireni Gorkha highway is seen to have had a major impact on these forests because great amounts of timber were needed in Gorkha. Transportation of timber by road made it possible to transport trees from areas farther away than was possible previously, and the forests were therefore degraded. Distance by road in this case is therefore likely to have played a major role at the time when Gorkha town was expanding – a time when forest regulations and enforcement were inadequate to keep up with the pace at which forest degradation took place. The decreasing timber-demand from Gorkha, together with restrictions on timber-extraction by the CF, has probably reduced the importance of the road in explaining forest degradation.

The current abundance of *Shorea* and *Schima* recruits does not reflect differences that can be explained according to the distance-gradient and increased disturbance as hypothesised. The same is true for walking time. Why does the current regeneration not seem to be affected by either km or walking time? I relate this result to Gorkha's limited role as a 'forest-product provider'. Fieldwork showed that forest-products were mostly extracted or bought from the CFs or from private land. This de-emphasises the influence of the market in Gorkha because users only rarely needed to go there to obtain forest-products. Based on these findings H_2 was rejected.

Although km and walking time did not matter, distance to plots from the villages situated alongside the road did. Longer distances increased the abundance of recruits. This finding is supported by Sapkota and Odén (2008), although it should be noted their study concerns fuelwood collection only. They found that fuelwood collection in CFs at Terai was significantly negatively related to distance: users close to a forest (< 3 km) collected four times the amount of fuelwood compared to distant users (> 3 km). Sapkota and Odén (2008) conclude that proximity to forests matters, an argument they build upon the simple logic that carrying products from remote areas increase the workload, the struggle and the time used per unit of extraction (Kerapeletswe & Lovett 2002 in Sapkota & Oden 2008). This is contrasted by findings from the Middle Hills in which it was found that increasing distances did not affect and hinder the obtainment of fuelwood. Adhikari et al. (2004a) explain this by the importance of fuelwood as a source of energy, and the difficulties of substituting it with other sources.

The significantly higher abundance of *Shorea* recruits in plots that were farther away from the main road and the major village settlement is interpreted as an effect of the greater effort needed to walk longer distances for each product-unit. As timber extraction and transportation over large distances are less important and prevalent than before, the main product extraction is related to fodder and firewood outtake mainly for local consumption. For as many as 84 % of the households in Gorkha district (+ 20 % compared to the national rate), firewood is the main source of fuel for cooking (CBS 2012). Timber collection was strictly regulated, while practices concerning the outtake and the amount of firewood and fodder varied between the forests. Firewood from green trees was collected and extracted mainly at times of thinning and pruning, while collection of fodder and dead wood was undertaken regularly, often on a daily basis. An implication from this is that time and energy used become important factors. I argue that reduced workload and the relatively less time consumed on product-extraction when undertaken close-by rather than faraway provide a reasonable explanation for the increasing number of *Shorea* recruits by distance from plot in Ludikhola. It indicates that the market does not play a crucial role in obtaining forest and livelihood products. Instead it suggests that the distance fodder and firewood collectors outstrip every day to feed their animals and to make fire for cooking determines which areas are most heavily used.

A factor that may explain why distance and walking time to Gorkha did not impact forest regeneration is that Gorkha is relatively easily reached from all the forests. Accessible transportation of people and products by road reduces the importance of walking, for whether one travels nine km or five km by road it does not make much difference. I therefore argue that accessibility by road reduces the impact of walking time, and that the limited range of distance by road makes no difference. To see an impact of road distance on forest regeneration would need greater distances between the forests, possibly also an extended time-lag. In addition, Gorkha played a limited role in providing forest-products or alternatives to the population.

It might also be that the importance of distance, as argued by Sapkota and Odén (2008), gets less important when the number of trees in private lands increases. Private land holding is highly correlated with wealth, which in the end might be the decisive factor. Further studies, which take number of farm trees and household wealth into account, will need to be undertaken to get a better picture of this situation.

Synthesising forest-population and forest-distance dynamics

None of the hypotheses ($H_{1\text{-}3}$) were accepted, and the null hypothesis was not falsified (Figure 5.1). Lack of evidence that regeneration is determined by user-density and market-proximity may indicate at least three things. First, variables that have not been evaluated are more important and overrule the effects of the studied variables. One such important factor might be household's wealth. Second, the sum of the very similar ecological settings and the similarities in the management system overrules the effects of differences in the measured variables on species responses. Last, but not least, Ostrom's belief in an individual's power to cope with common-pool resources in ways that are sustainable was strengthened by the fact that H_0 was not falsified, and her rationale needs further evaluation in this forest-case.

5.4 The success of CF management in regulating common-pool resources: implications of CF management in terms of forest sustainability

The severe degradation in Nepal (Eckholm 1975), although portrayed as a narrative and subsequently contrasted and downscaled (Ives 1987; 2004), is prominent in explaining the development of institutions and policies that concern resource management (Gilmour 1988), and specifically the development of CF management. Ludikhola watershed is interesting in these terms because it represents several typical events stretching from forest degradation, via implementation of management systems to forest regeneration.

Forest degradation in areas around Gorkha culminated in the late 1970s and 1980s according to CFUG's information. Forest degradation in these areas is tightly connected to the vast timber extraction from nearby forests during the development of Gorkha town, a process facilitated by the concurrent construction of Abu Khaireni Gorkha Highway. Forests close to Gorkha were degraded first because timber was most easily extracted and transported from these. While the CFUG in KP Bekhpari reported only limited impacts of the road establishment on forest degradation, CFUGs in Chisapani, Taksartari, Kuwadi and Birienchok noted that the establishment of the road had been a driving force in degradation because the easy transportation had facilitated timber extraction. The reason for the limited impacts on degradation of the road in the closest forest to Gorkha, KP Bekhpari, is that most good timber trees were already felled at the time when the road was established. I suggest this is a consequence of KP Bekhpari's relative proximity to Gorkha town, reached in less than 30 minutes by foot, i.e. accessible also before the road was completed. Neither in Mahalaxmi, the most distant forest from Gorkha, did the CFUG report that the road was a determining factor in degrading the forest. Its limited impact was related to the geographical structure of the forest. Most of the big timber trees were located downslope towards the river valley bottom. Trees were not carried from these sites to road due to the long distance. This information was verified through sampling in Mahalaxmi as the lower part of the forest was markedly older and characterized by bigger trees than those at the sampling elevation. Based on the discussion of the effects of distance on degradation and regeneration, I find it reasonable to conclude that forest degradation entails a spatial-gradient determined by distance from Gorkha and the road. Despite the spatial trend in forest degradation, I did not find a similar trend for forest regeneration, despite that the need to implement management to protect forests was first acknowledged precarious where the degradation was most severe, i.e. in the forests closest to Gorkha. The temporal implementation of management, starting in KP Bekhpari in 1990 and ending in Mahalaxmi in 1994, portrayed no discernible pattern in regeneration along this spatial-gradient. I argue this is understandable from the rather limited time span between the CF implementation in the various forests.

My findings show that the studied forests regenerate sustainably under the current management regime. Regrowth is influenced and explained by multiple factors, of which the introduction of CF management is indicated as one of the prime factors that have improved forest health in the study area. Improved environmental conditions under management by communities are supported in recent, influential literature (Varughese & Ostrom 2001; Gautam et al. 2002; Dev et al. 2003; Nagendra et al. 2008a; Tachibana & Adhikari 2009; Pandit & Bevilacqua 2011). Together with CF implementation, the reduction in timber extraction that followed the slowdown of the expansion of Gorkha town is likely a main factor that explains why forests now regenerate. The heavy degradation over two decades (*c* 1970 – 1990) meant that few good timber trees in accessible areas were actually left to be cut.

The total forest disturbance before CF management included, in addition to the extensive timber outtake, the regular types of disturbance referred to by Singh (1998) as ‘chronic disturbances’ such as firewood and fodder outtake. CF regulations prohibited and controlled the unregulated timber outtake in all forests, and restricted, to various degrees, the outtake of NTFPs. The sudden shift from almost ‘non-existent’ forest regulation to practically full regulation marks a decline in the forest-product outtake, especially of timber. The ‘chronic’ disturbance, still evident although somehow limited by restrictions on lopping and firewood collection, is seemingly within the forest carrying capacity as good indicators of regeneration were found. In spite of the fact that product outtake seems to be within the carrying capacity of the forests, Singh (1998) argues that ‘chronic’ disturbance may render forests inadequate time to recover, which in turn will exhaust forest resources. There is a possibility that the sharp reduction in forest-product outtake and the seemingly sustainable regeneration actually portray a situation of ‘false security’ for future forest regeneration in Ludikhola. For example, *Shorea*’s gregarious regrowth may possibly be explained by the sharp change in forest-product outtake, but the future development is unknown. A longer time-scale and a more thorough study of the outtake of NTFPs can help get a better picture of the possible influences of these activities now and in the future. This information is especially important in terms of sustaining future regeneration because product-extraction from forests on the verge of regeneration can have deleterious effects on them as they are especially prone to disturbances at this stage (Varughese & Ostrom 2001).

During the last decades, the belief in the success of forest management for sustaining common-pool resources has gained momentum. A multitude of different institutional arrangements exist (Ostrom 1999) and more research supports the idea that users have abilities to manage resources sustainably through institutions they are themselves responsible for (Ostrom 1999; Ostrom & Nagendra 2006). This was here studied in terms of CF. The likelihood that CF will be successful in sustaining resources depends upon people's commitments to these processes, which seems to be determined by the effect of CF on their livelihoods and the degree to which people they feel benefit from participation (Agrawal & Chhatre 2006; Ostrom & Nagendra 2006; Adhikari et al. 2007). Adhikari et al. (2007) argue that success of CF over some time improves the general environmental conditions and the forest health. As this increases the amount of forest products available, it is also believed to improve people's livelihoods. Community conservation is not a 'cure-all' – there are no guarantees that handing over forests for local government will necessarily sustain forest resources (Ostrom & Nagendra 2006). Despite this, growing evidence supports that a single governance arrangement will prevent non-sustainable resource use in all situations. This is well-summarized by Ostrom and Nagendra (2006 p 19230) who argue that "(…)the earlier assumption that no users would voluntarily contribute to making rules or enforcing them is false. On the other hand, assuming that all individuals will cooperate to solve resource dilemmas under all conditions is also false".

The willingness of people to self-organize and sustain a common property regime can be studied through group heterogeneities (Varughese & Ostrom 2001), such as differences in sociocultural backgrounds, interests and endowments. There are certain variables of heterogeneity, e.g. wealth and sociocultural differences, which Varughese and Ostrom (2001) have considered which I have not. Although the studied human-ecological variables of this study did not impact regeneration, there is a chance that other factors, such as wealth, out-migration and ethnicity may affect forest regeneration. If that is true, I am in danger of committing a type II error when arguing these factors are not likely to determine the sustainability of the 'commons' within the studied forests because these seem to be controlled by the management system. The point here, however, is that heterogeneities between and within groups, here mediated through user-density and distance to Gorkha, did not determine the effects of the group to sustain the common resource and H_1 and H_2 were therefore rejected. I argue that small differences in practices concerning forest management were more important to explain the abundance of recruits, *cf*. *Shorea* in Chisapani and *Schima* in KP Bekhpari, than underlying heterogeneities between and within the forests and their users. In line with Varughese and Ostrom's argument (2001), sustainable forest regrowth in the studied forests might then actually express that the CF management in these forests is successful in monitoring the heterogeneities between the users and the forests.

I argue that this study adds evidence and support to Ostrom and Nagendra's (2006) findings by showing that CF is successful in sustaining forest resources in the studied forests (Figure 5.1). The users are engaged in sustaining the forests and they monitor each other's use by ensuring a rotational forest guard system exists; by helping out with various management activities such as thinning and making of fire-breaks; and by participating in meetings and formal settings for decision making. It is likely that these factors contribute to, and increase the chances of CF success, and I consider them important in reducing the 'chronic' disturbance for which we do not know the future results. Hardin's (1968) hypothesis is rejected because 'commons' were sustainably managed through CF. The fact that Ostrom's rationale could not be falsified implies that her work in understanding the complex realities of managing 'commons' is important for the future forest management.

5.5 Critical assessment of the applied methods

Sample plots were located by a systematic approach based on two main factors: elevation contours and distance in straight line from one plot to the next (Figure 3.2). It is obvious that selection of some sort is inevitable as individuals and populations are otherwise too extensive and numerous to be covered completely. However "Neither random nor systematic spatial sampling is practicable in most field studies" (Borradaile 2003 p 4), and misinterpretations in sampling may arise from biased sampling, i.e. non-random sampling (Jager & Looman 1995). The decision to sample within a limited elevation range increased the efficiency of sampling, and in addition reduced the effect of elevation on the species. This sampling method was chosen although nature varies, and despite that sampling along contours naturally limits which areas are covered. It is clear that this sample design resulted in an inappropriate representation of areas other than those along the contours *cf*. Waite's (2000). The systematic element was mainly captured by the contours, because although it was approximately predefined how many metres there should be between the plots, it was random and unbiased where the plot was laid down due to exclusion areas and the criterion of centring the plot on a mature tree. Despite a lack of data and evidence for this argument, my impression from the field is that due to the biological similarities in the five forests at approximately similar elevations, random sampling within these forests would not render a regeneration pattern which was significantly different from the one outlined by this study.

As noted, the number of plots in each percent interval was not equal for all the variables, but normally highest around average. Accumulation of observations within a certain variable range (often), and the lack of representations of certain intervals, may imply some bias in the results. An ideal sampling design would have approximately equal number of plots within each sampling interval, but this requires a subjective sampling, which was not applicable for in terms of securing the ‘random component’ . The systematic sampling was rather random with respect to what kind of disturbance level that was found in the plot.

The criterion that each plot should be centred on a mature tree was done to ensure that the forest area was a suitable location for studying regeneration. The mature tree indicated that this area was a pre-forested area that had undergone deforestation and that, at the current time, was undergoing forest regrowth. From a landscape ecological viewpoint, however, choosing a centre tree was not tenable. This is because seedlings are generally more abundant immediately below the mature tree. In a study of regeneration this might be misleading. Another consequence is that presence of a mature tree in each plot is likely to increase the estimates of the canopy closure above the ‘real’ level as there would not be a mature tree in every randomly sampled plot.

This study is one-point in time, meaning that the results are merely a snapshot of the current regeneration. In order to evaluate and predict the sustainability of future forest regeneration this study ought to be elaborated to include at least two periods of forest sampling. Sampling a second time would allow the following up on regeneration trends, it would provide a better foundation for inferring influences on species establishment by an older, and probably denser, tree structure, and as well provide information on the long-term effects of ‘chronic’ disturbances on the species. It would be interesting to conduct a similar forest sampling in a government-forest to see if *Shorea* regeneration is gregarious there too, or if ‘absent’ management implies greater disturbance and hence less forest regeneration.

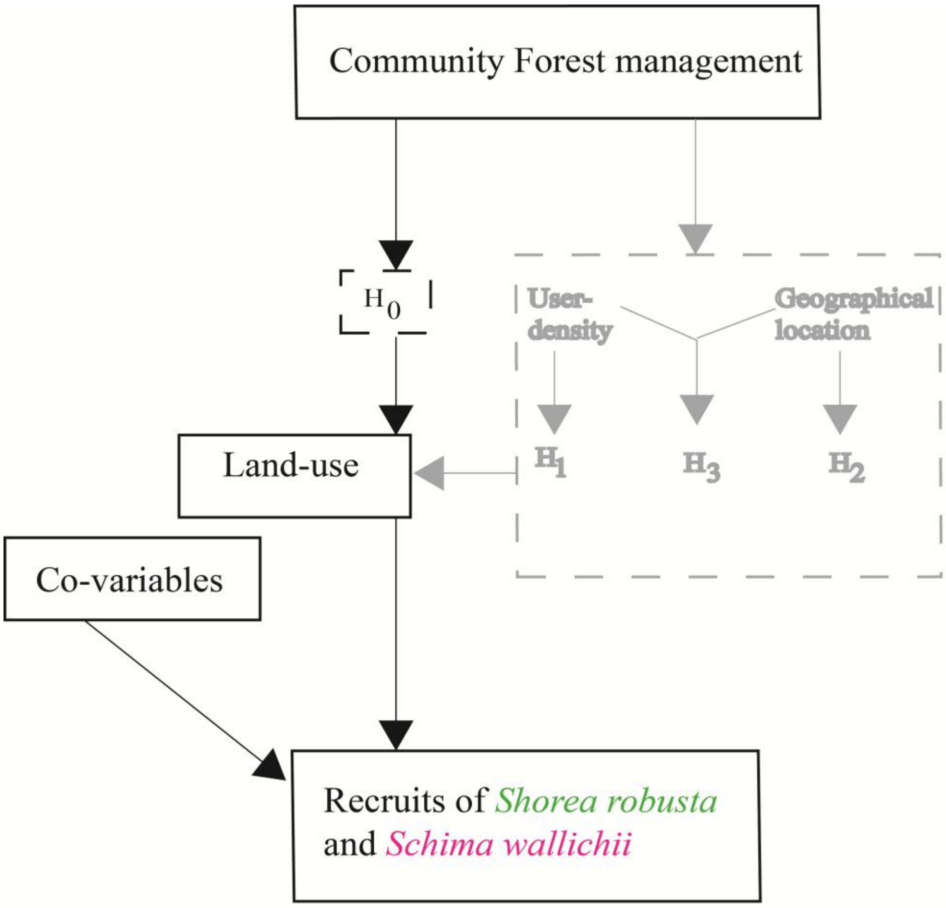


Figure 5.1: Summarizing the evidenced effects of CF management on regeneration of *Shorea robusta* and *Schima wallichii*. Whereas regeneration of both species was influenced by land-use explanatory variables and co-variables: regeneration was independent of changing human-ecological gradients, *cf*. H_0. H_1-H_3 (greyed out) were rejected. Significance denoted by *=p<0.05; **=p<0.01; colour reflect influenced species. Land-use: canopy closure*, litter cover*, lopping degree*/**, number of cut stems*. Co-variables: soil moisture*/**, Relative Radiation Index*, masl.

CHAPTER 6 CONCLUSIONS

Forest regeneration in all the forests was sustainable under CF management. This was true for the overall and the forest-wise regeneration. These results were independent of user-density and market accessibility, factors which may influence the rate and amount of forest-product extraction, and hence forest disturbance. This indicates that CF has been successful in regulating forest-product outtake, despite the unstable political situation in Nepal. This argument is supported and strengthened by several individual findings:

- The forest structure indicated healthy forests with more young than mature trees.
- Seedlings were more abundant than saplings; and saplings were more abundant than trees in the smallest size-class (DBH 5-10 cm).
- The current levels of disturbance seem to be within the forest carrying capacity as regeneration is sustainable, although *Shorea* especially was prone to disturbances.
- H_1, H_2 and H_3 were rejected by quantitative analysis, meaning that user-density and market accessibility were not found to influence forest regeneration.
- The occurrence of fire was reduced under CF management due to awareness raising in the $REDD^+$-programme, a factor which probably increased the establishment of recruits.
- Despite the similar management, some differences in practices were evident. Restrictions on thinning and lopping in Chisapani and KP Bekhpari exemplify practices which seem to favour regeneration, shown by the significantly higher abundance of recruits of *Shorea* and *Schima,* respectively.

The current findings add to a growing body of literature on forest regeneration in the Middle Hills of Nepal, a result which by many is credited to the widespread interest and development of various common-pool resource management systems. Despite the many ways to manage resources sustainably, the current study only examined common-pool resource management through CF, a system which was successful in sustaining these forests. Findings support Ostrom's theory by acknowledging that forest users organized in communities have abilities to regulate and sustain forests by bottom-up, local management initiated and regulated by themselves. It would be interesting to assess if forest regeneration in Ludikhola watershed is prevalent *disregarding* a common-pool resource management system to allow the further discussion on the theories of Hardin and Ostrom.

REFERENCES

Aase, T & Vetaas, O (2007) Risk Management by Communal Decision in Trans-Himalayan Farming: Manang Valley in Central Nepal. *Human Ecology,* 35**,** 453-460.

Aase, T H & Fossåskaret, E (2007) *Skapte virkeligheter. Om produksjon og tolkning av kvalitative data.* Oslo, Universitetsforlaget.

Acácio, V; Holmgren, M; Jansen, P A & Schrotter, O (2007) Multiple recruitment limitation causes arrested succession in Mediterranean cork oak systems. *Ecosystems,* 10**,** 1220-1230.

Acharya, K P (2002) Twenty-four years of community forestry in Nepal. *International Forestry Review,* 4**,** 149-156.

Adhikari, B; Di Falco, S & Lovett, J C (2004a) Household characteristics and forest dependency: evidence from common property forest management in Nepal. *Ecological Economics,* 48**,** 245-257.

Adhikari, B; Williams, F & Lovett, J C (2007) Local benefits from community forests in the middle hills of Nepal. *Forest Policy and Economics,* 9**,** 464-478.

Adhikari, M; Nagata, S & Adhikari, M (2004b) Rural household and forest: an evaluation of household's dependency on community forest in Nepal. *Journal of Forest Research,* 9**,** 33-44.

Agrawal, A & Chhatre, A (2006) Explaining success on the commons: Community forest governance in the Indian Himalaya. *World Development,* 34**,** 149-166.

Allan, N J R (1986) Accessibility and Altitudinal Zonation Models of Mountains. *Mountain Research and Development,* 6**,** 185-194.

Austin, M P; Nicholls, A O & Margules, C R (1990) Measurement of the Realized Qualitative Niche: Environmental Niches of Five Eucalyptus Species. *Ecological Monographs,* 60**,** 161-177.

Baral, S & Katzensteiner, K (2009) Diversity of vascular plant communities along a disturbance gradient in a central mid-hill community forest of Nepal. *Banko Janakari,* 19**,** 3-10.

Bjønness, I-M (1983) External Economic Dependency and Changing Human Adjustment to Marginal Environment in the High Himalaya, Nepal. *Mountain Research and Development,* 3**,** 263-272.

Blaikie, P & Springate-Baginski, O (eds.) (2007) *Forests, people and power: the political ecology of reform in South Asia.* London, Earthscan.

Borradaile, G J (2003) *Statistics of earth science data: their distribution in time, space, and orientation.* Berlin, Springer.

Boserup, E (1965) *The conditions of agricultural growth: the economics of agrarian change under population pressure.* Chicago, Aldine Publishing Company.

Brundtland, G H (1987) Report of the World Commission on Environment and Development - Our Common Future. Oslo.

Byers, A (1987) An Assessment of Landscape Change in the Khumbu Region of Nepal Using Repeat Photography. *Mountain Research and Development,* 7**,** 77-81.

Carpenter, C (2005) The Environmental Control of Plant Species Density on a Himalayan Elevation Gradient. *Journal of Biogeography,* 32**,** 999-1018.

CBS (2012) National Population and Housing Census 2011. Government of Nepal. National Planning Commission Secretariat. Kathmandu.

Chaudhary, R P (2000) Forest conservation and environmental management in Nepal: a review. *Biodiversity and Conservation,* 9**,** 1235-1260.

Chhetri, B B K; Larsen, H O & Smith-Hall, C (2012) Law Enforcement in Community Forestry: Consequences for the Poor. *Small-scale Forestry,* 11**,** 435-452.

CIA (2013) *Nepal* [Online]. Washington D.C: Central Intelligence Agency. Available: https://www.cia.gov/library/publications/the-world-factbook/geos/np.html [Accessed 21.10.2012]

Community Forest User Group & District Forest Office (1990-1994) Operational Plan. District Forest Office.

Condit, R; Sukumar, R; Hubbell, Stephen P & Foster, Robin B (1998) Predicting Population Trends from Size Distributions: A Direct Test in a Tropical Tree Community. *The American Naturalist*, 152**,** 495-509.

Department of Forest (2011) Community Forestry Division - CFUG Database Record. Kathmandu.

Department of Hydrology and Meteorology (2012) Rainfall Data. Temperature Data. Kathmandu.

Dev, O P; Yadav, N P; Springate-Baginski, O & Soussan, J (2003) Impacts of Community Forestry on Livelihoods in the Middle Hills of Nepal. *Journal of Forest and Livelihood,* 3**,** 64-77.

Eckholm, E P (1975) The Deterioration of Mountain Environments. *Science,* 189**,** 764-770.

Ellis, E C; Klein Goldewijk, K; Siebert, S; Lightman, D & Ramankutty, N (2010) Anthropogenic transformation of the biomes, 1700 to 2000. *Global Ecology and Biogeography,* 19**,** 589-606.

ESRI (2012) ArcGIS. 10.0. ed. Redlands, USA.

FAO (2000) FRA 2000 On a definition of forest and forest change. Working paper 33 ed. Rome.

FAO (2008) *What is Sustainable Forest Management?* [Online]. Available: http://www.fao.org/forestry/sfm/24447/en/ [Accessed 04.01 2013].

FAO (2010a) Global Forest Resources Assessment. Main report. Rome.

FAO (2010b) Global Forest Resources Assessment. Terms and Definitions. Working Paper 144/E. Rome: Forestry Department.

FAO (2011) *State of the World's Forests.* Rome.

FAO (2012) *State of the World's Forests.* Rome.

Fossen, H (2008) *Geologi: stein, mineraler, fossiler og olje.* Bergen, Fagbokforlaget.

Fowler, J; Cohen, L & Jarvis, P (1998) *Practical statistics for field biology.* Chichester, Wiley.

Fox, J (1993) Forest Resources in a Nepali Village in 1980 and 1990: The Positive Influence of Population Growth. *Mountain Research and Development,* 13**,** 89-98.

Gautam, A P; Shivakoti, G P & Webb, E L (2004) A Review of Forest Policies, Institutions, and Changes in the Resource Condition in Nepal. *International Forestry Review,* 6**,** 136-148.

Gautam, A P; Webb, E L & Eiumnoh, A (2002) GIS Assessment of Land Use/Land Cover Changes Associated With Community Forestry Implementation in the Middle Hills of Nepal. *Mountain Research and Development,* 22**,** 63-69.

Gautam, C M & Watanabe, T (2005) Composition, distribution and diversity of tree species under different management systems in the hill forests of Bharse Village, Gulmi District, Western Nepal. *Himalayan Journal of Sciences,* 3**,** 67-74.

Gautam, K H (2001) *Lopping regimes in community-managed Sal (Shorea robusta) forests of Nepal: prospects for multiple-product silviculture for community forestry.* Doctor of Philosophy, University of Canterbury.

Gautam, K H & Devoe, N N (2006) Ecological and anthropogenic niches of sal (*Shorea robusta* Gaertn. f.) forest and prospects for multiple-product forest management – a review. *Forestry,* 79**,** 81-101.

Gilmour, D A (1988) Not seeing the trees for the forest: a re-appraisal of the deforestation crisis in two hill districts of Nepal. *Mountain Research and Development,* 8**,** 343-350.

Gilmour, D A (2003) Retrospective and prospective view of community forestry in Nepal. *Journal of Forest and Livelihood,* 2**,** 5-7.

Goff, F G & West, D (1975) Canopy-understory interaction effects on forest population structure. *Forest Science,* 21**,** 98-107.

Google Earth (2010) *Nepal* [Online]. Available: http://www.google.com/earth/index.html

Goswami, S (2012) Seed sterility and germination problems in *Schima wallichii* (DC.) Korth. and *S. khasiana* (Dyer) Bloemb. *Keanean Journal of Science*, 1.

Graner, E (1997) *The political ecology of community forestry in Nepal.* Saarbrücken, Verlag für Entwicklungspolitik.

Grime, J P (1979) *Plant Strategies & Vegetation Processes.* Chichester, John Wiley & Sons.

Guthman, J (1997) Representing Crisis: The Theory of Himalayan Environmental Degradation and the Project of Development in Post-Rana Nepal. *Development and Change,* 28**,** 45-69.

Hagen, T (1969) *Report on the geological survey of Nepal, 1, Preliminary reconnaissance.* Basel, Birkhäuser.

Hardin, G (1968) The Tragedy of the Commons. *Science,* 162**,** 1243-1248.

Harper, J L & White, J (1974) The Demography of Plants. *Annual Review of Ecology and Systematics,* 5**,** 419-463.

Hawkins, B A (2012) Eight (and a half) deadly sins of spatial analysis. *Journal of Biogeography,* 39**,** 1-9.

Hawkins, B A; Diniz-Filho, J A F; Mauricio Bini, L; De Marco, P & Blackburn, T M (2007) Red herrings revisited: spatial autocorrelation and parameter estimation in geographical ecology. *Ecography,* 30**,** 375-384.

Hobbs, R J & Huenneke, L F (1992) Disturbance, Diversity, and Invasion: Implications for Conservation. *Conservation Biology,* 6**,** 324-337.

ICIMOD (2010) *LudiKhola watershed, Gorkha District. GIS Map Layers*. Kathmandu: ICIMOD.

ICIMOD; ANSAB & FECOFUN (2010) Report on Forest Carbon Stock of Community Forests in three Watersheds (Ludikhola, Kayarkhola and Charnawati).

IFRI (2013) *International Forestry Resources and Institutions (IFRI) - About us* [Online]. Michigan: School of Natural Resources and Environment. Available: http://www.ifriresearch.net/ [Accessed 16.04. 2013].

Ingram, J C; Whittaker, R & Dawson, T (2005) Tree Structure and Diversity in Human-Impacted Littoral Forests, Madagascar. *Environmental Management,* 35**,** 779-798.

IPCC (2000) Special report: Land Use, Land-Use Change, and Forestry. Summary for Policymakers. WMO/UNEP.

Ives, J D (1987) The Theory of Himalayan Environmental Degradation: Its Validity and Application Challenged by Recent Research. *Mountain Research and Development,* 7**,** 189-199.

Ives, J D (2004) Himalayan perceptions: Environmental change and the well-being of mountain peoples. *Himalayan Journal of Sciences,* 2**,** 17-19.

Jager, J C & Looman, C W N (1995) Data collection. *In:* Jongman, Braak & Tongeren (eds.) *Data analysis in community and landscape ecology.* Cambridge University Press.

Jennings, S B; Brown, N D & Sheil, D (1999) Assessing forest canopies and understorey illumination: canopy closure, canopy cover and other measures. *Forestry,* 72**,** 59-73.

Lambrechts, C; Wilkie, M L; Rucevska, I & Sen, M (2009) Vital Forest Graphics. UNEP, FAO, UNFF.

Lamichane, B R (2008) *Dynamics and Driving Forces of Land Use/Forest Cover Change and Indicators of Climate Change in a Mountain Sub-Watershed of Gorkha.* Master thesis, Tribhuvan University, Pokhara.

Lamichane, B R & Awasthi, K D (2009) Changing Climate in a Mountain Sub-watershed in Nepal. *Journal of Forest and Livelihood,* 8**,** 99-105.

Legendre, P (1993) Spatial Autocorrelation: Trouble or New Paradigm? *Ecology,* 74**,** 1659-1673.

Mahat, T B S; Griffin, D M & Shepherd, K R (1986) Human Impact on Some Forests of the Middle Hills of Nepal 1. Forestry in the Context of the Traditional Resources of the State. *Mountain Research and Development,* 6**,** 223-232.

Mauricio Bini, L; Diniz-Filho, J A F; Rangel, T F L V B; Akre, T S B; Albaladejo, R G; Albuquerque, F S; Aparicio, A; Araújo, M B; Baselga, A; Beck, J; Isabel Bellocq, M; Böhning-Gaese, K; Borges, P A V; Castro-Parga, I; Khen Chey, V; Chown, S L; De Marco, J P; Dobkin, D S; Ferrer-Castán, D; Field, R; Filloy, J; Fleishman, E; Gómez, J F; Hortal, J; Iverson, J B; Kerr, J T; Daniel Kissling, W; Kitching, I J; León-Cortés, J L; Lobo, J M; Montoya, D; Morales-Castilla, I; Moreno, J C; Oberdorff, T; Olalla-Tárraga, M Á; Pausas, J G; Qian, H; Rahbek, C; Rodríguez, M Á; Rueda, M; Ruggiero, A; Sackmann, P; Sanders, N J; Carina Terribile, L; Vetaas, O R & Hawkins, B A (2009) Coefficient shifts in geographical ecology: an empirical evaluation of spatial and non-spatial regression. *Ecography,* 32**,** 193-204.

McCune, B & Keon, D (2002) Equations for potential annual direct incident radiation and heat load. *Journal of Vegetation Science,* 13**,** 603-606.

McDonald, J H (2009) *Handbook of Biological Statistics.* Baltimore, Maryland, Sparky House Publisher

McManus, M; Farrar, D & Alexander, L (2012) *Autocorrelation and Data Independence: Details* [Online]. United States Environmental Protection Agency. Available: http://www.epa.gov/caddis/da_principles_2.html [Accessed 23.11 2012].

Meilby, H & Puri, L (2007) Features and allometric relationships characterising trees on farmland–an example from Chainpur VDC, Chitwan. *Banko Janakari,* 17**,** 18-26.

Millennium Ecosystem Assessment (2005) *Ecosystems and Human Well-being.* Washington, D.C.

Ministry of Forests and Soil Conservation (1993) Forest Act 2049 (1993) and Forest Regulation 2051 (1995). Katmandu HMGN/USAID.

Ministry of Forests and Soil Conservation (2002) *Forest and vegetation types of Nepal.* Kathmandu, Tree Improvement and Silviculture Component.

Moench, M & Bandyopadhyay, J (1986) People-Forest Interaction: A Neglected Parameter in Himalayan Forest Management. *Mountain Research and Development,* 6**,** 3-16.

Molofsky, J & Augspurger, C K (1992) The Effect of Leaf Litter on Early Seedling Establishment in a Tropical Forest. *Ecology,* 73**,** 68-77.

Måren, I E & Vetaas, O R (2007) Does Regulated Land Use Allow Regeneration of Keystone Forest Species in the Annapurna Conservation Area, Central Himalaya? *Mountain Research and Development,* 27**,** 345-351.

Nábělek, J; Hetényi, G; Vergne, J; Sapkota, S; Kafle, B; Jiang, M; Su, H; Chen, J; Huang, B-S & Team, t H-C (2009) Underplating in the Himalaya-Tibet Collision Zone Revealed by the Hi-CLIMB Experiment. *Science,* 325**,** 1371-1374.

Nabuurs, G J; Masera, O; Andrasko, K; Benitez-Ponce, P; Boer, R; Dutschke, M; Elsiddig, E; Ford-Robertson, J; Frumhoff, E; Karjalainen, T; Krankina, O; Kurz, W A; Matsumoto, M; Oyhantcabal, W; Ravindranath, N H; Sanz Sanchez, M J & Zhang, X (2007) Contribution of Working Group III to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change. Chapter 9. *In:* B. Metz, O.R. Davidson, P.R. Bosch, R. Dave & L.A. Meyer (eds.). Cambridge, United Kingdom and New York, USA: Cambridge University Press.

Nagendra, H (2007) Drivers of reforestation in human-dominated forests. *Proceedings of the National Academy of Sciences,* 104**,** 15218-15223.

Nagendra, H; Karmacharya, M & Karna, B (2005) Evaluating forest management in Nepal: Views across space and time. *Ecology and Society,* 10**,** 24.

Nagendra, H & Ostrom, E (2011) The challenge of forest diagnostics. *Ecology and Society,* 16**,** 20.

Nagendra, H; Pareeth, S; Sharma, B; Schweik, C & Adhikari, K (2008a) Forest fragmentation and regrowth in an institutional mosaic of community, government and private ownership in Nepal. *Landscape Ecology,* 23**,** 41-54.

Nagendra, H; Pareeth, S; Sharma, B; Schweik, C M & Adhikari, K R (2008b) Forest fragmentation and regrowth in an institutional mosaic of community, government and private ownership in Nepal. *Landscape Ecology,* 23**,** 41-54.

Nicholas, C; Shaun, F & Gill, V (2010) *Key methods in geography.* Thousand Oaks, California, SAGE.

Ohsawa, M; Shakya, P R & Numata, M (1986) Distribution and Succession of West Himalayan Forest Types in the Eastern Part of the Nepal Himalaya. *Mountain Research and Development,* 6**,** 143-157.

Oke, T R (1987) *Boundary layer climates.* London, Methuen.

Orwa, C; Kindt, R; Jamnadass, R & Simons, A (2009a) *Agroforestree Database: a tree reference and selection guide. Schima Wallichii* [Online]. World Agroforestry Centre. Available: https://www.google.com/url?q=http://www.worldagroforestry.org/treedb2/AFTPDFS/Schima_wallichii.pdf&sa=U&ei=1wuSUaHNNYeGhQeSz4CwDQ&ved=0CAcQFjAA&client=internal-uds-cse&usg=AFQjCNGvDaVfjEtHR2lug5A1VDbYFtGFKA [Accessed 06.03 2012].

Orwa, C; Mutua, A; Kindt, R; Jamnadass, R & Simons, A (2009b) *Agroforestree Database: a tree reference and selection guide. Shorea robusta* [Online]. Word Agroforestry Centre. Available: https://www.google.com/url?q=http://www.worldagroforestry.org/treedb2/AFTPDFS/Shorea_robusta.pdf&sa=U&ei=IAySUdG6KIXg7Qbcr4GoCg&ved=0CAcQFjAA&client=internal-uds-cse&usg=AFQjCNF1Oqx6ACQHFmQpBUxpP-KbWMCg3A [Accessed 05.03 2012].

Ostrom, E (1999) Coping with tragedies of the commons. *Annual review of political science,* 2**,** 493-535.

Ostrom, E (2005) *Understanding institutional diversity.* Princeton, New Jersey, Princeton University Press.

Ostrom, E (2008) International Forestry Resources and Institutions (IFRI) Research Program fieldmanual. Michigan: School of Natural Resources.

Ostrom, E; Gardner, R & Walker, J (1994) *Rules, games, and common-pool resources.* Ann Arbor, University of Michigan Press.

Ostrom, E & Moran, E F (2005) *Seeing the forest and the trees: human-environment interactions in forest ecosystems.* Cambridge, Massachusetts, MIT Press.

Ostrom, E & Nagendra, H (2006) Insights on linking forests, trees, and people from the air, on the ground, and in the laboratory. *Proceedings of the National Academy of Sciences of the United States of America*, 103**,** 19224-19231.

Pandit, R & Bevilacqua, E (2011) Forest users and environmental impacts of community forestry in the hills of Nepal. *Forest Policy and Economics,* 13**,** 345-352.

Paudyal, K R; Pokharel, T P & Paudel, L P (2011) Petrography and illite crystallinity of the Lesser Himalayan metasediments, Gorkha Narayangarh section, central Nepal. *Bulletin of the Department of Geology, Tribhuvan University, Kathmandu, Nepal,* 14**,** 67-76.

Pickett, S T A & White, P S (1985) *The Ecology of natural disturbance and patch dynamics.* Orlando, Fla., Academic Press.

Pokharel, B K; Branney, P; Nurse, M & Malla, Y B (2007) Community forestry: Conserving forests, sustaining livelihoods and strengthening democracy. *Journal of Forest and Livelihood*, 6**,** 8-19.

Polunin, O & Stainton, A (1984) *Flowers of the Himalaya.* Dehli, Oxford University Press.

Putz, F E & Canham, C D (1992) Mechanisms of arrested succession in shrublands: root and shoot competition between shrubs and tree seedlings. *Forest Ecology and Management,* 49**,** 267-275.

Putz, F E & Redford, K H (2010) The Importance of Defining 'Forest': Tropical Forest Degradation, Deforestation, Long-term Phase Shifts, and Further Transitions. *Biotropica,* 42**,** 10-20.

Rangel, T F; Diniz-Filho, J A F & Bini, L M (2010) Spatial Analyses in Macroecology. 4.0. ed.

Rangel, T F L V B; Diniz-Filho, J A F & Bini, L M (2006) Towards an integrated computational tool for spatial analysis in macroecology and biogeography. *Global Ecology and Biogeography,* 15**,** 321-327.

Rautinainen, O & Suoheimo, J (1998) *Shorea Robusta* Gaertn.f.(Sal) in the forestry of Nepal. *Thai Journal of Forestry,* 17**,** 43-54.

Rubin, B D; Manion, P D & Faber-Langendoen, D (2006) Diameter distributions and structural sustainability in forests. *Forest Ecology and Management,* 222**,** 427-438.

Rykiel, E J (1985) Towards a definition of ecological disturbance. *Australian Journal of Ecology,* 10**,** 361-365.

Sagar, R & Singh, J (2004) Local plant species depletion in a tropical dry deciduous forest of northern India. *Environmental Conservation,* 31**,** 55-62.

Sapkota, I (2009) *Species diversity, regeneration and early growth of Sal forests in Nepal.* Doctor of Science Doctoral Thesis, Sveriges lantbruksuniversitet.

Sapkota, I & Oden, P (2008) Household characteristics and dependency on community forests in Terai of Nepal. *International Journal of Social Forestry,* 1**,** 123-144.

Sapkota, I; Tigabu, M & Odén, P C (2009) Tree diversity and regeneration of community-managed Bhabar lowland and Hill Sal forests in central region of Nepal. *Bois et forêts des tropiques,* 300**,** 12.

Sarmiento, F O (1997) Arrested succession in pastures hinders regeneration of Tropandean forests and shreds mountain landscapes. *Environmental Conservation,* 24**,** 14-23.

Saxena, A K & Singh, J S (1984) Tree Population Structure of Certain Himalayan Forest Associations and Implications concerning Their Future Composition. *Vegetatio,* 58**,** 61-69.

Schroeder, R F (1985) Himalayan Subsistence Systems: Indigenous Agriculture in Rural Nepal. *Mountain Research and Development,* 5**,** 31-44.

Shrestha, B B (2005) Fuelwood harvest, management and regeneration of two community forests in Central Nepal. *Himalayan Journal of Sciences,* 3**,** 75-80.

Shrestha, B P (1989) *Forest plants of Nepal.* Lalitpur, Educational Enterprise Pvt. Ltd.

Singh, J & Singh, S (1987) Forest vegetation of the Himalaya. *The Botanical Review,* 53**,** 80-192.

Singh, J S & Singh, S P (1992) *Forests of Himalaya: structure, functioning, and impact of man.* Nainital, Gyanodaya Prakashan.

Singh, S P (1998) Chronic disturbance, a principal cause of environmental degradation in developing countries. *Environmental Conservation,* 25**,** 1-2.

SPSS Inc (2009) PASW Statistics. 18.0. ed. Hong Kong.

Storrs, A & Storrs, J (1990) *Trees and shrubs of Nepal and the Himalayas.* Kathmandu, Pilgrims Book House.

Suresh, M; Bhawani, S D & Gehendra, B G (2009) Temporal and spatial variability of climate change over Nepal (1976 - 2005). Kathmandu: Practical Action Nepal Office.

Svensson, J S & Jeglum, J K (2001) Structure and dynamics of an undisturbed old-growth Norway spruce forest on the rising Bothnian coastline. *Forest Ecology and Management,* 151**,** 67-79.

Tachibana, T & Adhikari, S (2009) Does Community-Based Management Improve Natural Resource Condition? Evidence from the Forests in Nepal. *Land Economics,* 85**,** 107-131.

Thoms, C A (2008) Community control of resources and the challenge of improving local livelihoods: A critical examination of community forestry in Nepal. *Geoforum,* 39**,** 1452-1465.

Timilsina, N; Ross, M S & Heinen, J T (2007) A community analysis of sal (*Shorea robusta*) forests in the western Terai of Nepal. *Forest Ecology and Management,* 241**,** 223-234.

Tobler, W R (1970) A Computer Movie Simulating Urban Growth in the Detroit Region. *Economic Geography,* 46**,** 234-240.

Troup, R S (1975a) *The Silviculture of Indian trees I.* Dehli, Forest Research Institute.

Troup, R S (1975b) *The Silviculture of Indian trees II.* Dehli, Forest Research Institute.

Turner, M G; Collins, S L; Lugo, A L; Magnuson, J J; Rupp, T S & Swanson, F J (2003) Disturbance Dynamics and Ecological Response: The Contribution of Long-Term Ecological Research. *BioScience,* 53**,** 46-56.

United Nations (2011) *Celebrating Forests for People* [Online]. Available: http://www.un.org/en/events/iyof2011/

United Nations Development Program (2013) Summary of Human Development Report 2013. The Rise of the South: Human Progress in a Diverse World. New York, USA.

van der Maarel, E (1993) Some Remarks on Disturbance and Its Relations to Diversity and Stability. *Journal of Vegetation Science,* 4**,** 733-736.

Varughese, G (2000) Population and Forest Dynamics in the Hills of Nepal: Institutional Remedies by Rural Communities. *In:* Gibson, C C, McKean, M A & Ostrom, E (eds.) *People and forests: communities, institutions, and governance.* Cambridge, Massachusetts, London, MIT Press.

Varughese, G & Ostrom, E (2001) The Contested Role of Heterogeneity in Collective Action: Some Evidence from Community Forestry in Nepal. *World Development,* 29**,** 747-765.

Vetaas, O R (1992) Gradients in field-layer vegetation on an arid misty mountain plateau in the Sudan. *Journal of Vegetation Science,* 3**,** 527-534.

Vetaas, O R (1997) The effect of canopy disturbance on species richness in a central Himalayan oak forest. *Plant Ecology,* 132**,** 29-38.

Vetaas, O R (2000a) Comparing species temperature response curves: population density versus second-hand data. *Journal of Vegetation Science,* 11**,** 659-666.

Vetaas, O R (2000b) The effect of environmental factors on the regeneration of *Quercus semecarpofolia* Sm. in Central Himalaya, Nepal. *Plant Ecology* 146**,** 137-144.

Vetaas, O R & Ferrer-Castán, D (2008) Patterns of woody plant species richness in the Iberian Peninsula: environmental range and spatial scale. *Journal of Biogeography,* 35**,** 1863-1878.

Waite, S (2000) *Statistical ecology in practice: a guide to analysing environmental and ecological field data.* Harlow, Pearson Education.

Weller, D E (1987) Self-thinning exponent correlated with allometric measures of plant geometry. *Ecology***,** 813-821.

West, D C; Shugart, H H & Ranney, J W (1981) Population Structure of Forests Over a Large Area. *Forest Science,* 27**,** 701-710.

Whittaker, R H (1967) Gradient analysis of vegetation. *Biological Reviews,* 42**,** 207-264.

Williams, M (2006) *Deforesting the earth: from prehistory to global crisis: an abridgment.* Chicago, University of Chicago Press.

World Bank (1979) Nepal - Development Performance and Prospects. Washington, D.C. USA.

APPENDIX

Appendix 1: Information from interviews concerning forest background (1-4) and forest product-use and -regulation.

	Mahalaxmi	Birienchok	Kuwadi	Taksartari	Chisapani	KP Bekhpari
CF Background Info						
Establishment[2]	1994	1992	1992	1993	1992	1990
Area (Ha)[1]	63.96	83.57	92.27	89.31	50.04	51.15
Households (Hh)[1;3]	71 (pre *c* 2005; 130)	185	120, used by 50 %	105	92	230
User-density = $^{Hh}/_{Ha}$	1.11	2.21	0.65	1.18	1.83	4.50
Appr. distance to Gorkha by road (km)[4]**/ Time to walk**[3]	9.6/120	9.0/100	7.8/60	7.2/60	6.5/90	5.0/30
Forest History						
Hand-over status	Degraded. Only few, scattered and deformed trees left on the upper slope. Downslope some big trees.	Degraded, especially along the roadside where only few and scattered trees were left. Some big trees remained downslope.	Degraded. Seedlings and saplings lacked. Only bush and scattered trees were left.	Degraded. The construction of Gorkha bazaar and the need for timber left only few trees.	Degraded. Only few and scattered big trees were left. Described as a "desert".	Degraded because of heavy cutting when there was "open access" to the forest. Especially big Sal trees were cut.
Species priority at time of hand-over	Sal and Chilaune were protected. Other	Sal and Chilaune were protected. Other	Sal was given protection priority.	No specific species were prioritized, but	By rule no specific species were	Sal was given protection priority.

	species cut for firewood. Biodiversity perspective now.	species were cut for fodder and firewood. Biodiversity perspective now.	Biodiversity perspective now.	Sal, Chilaune and Saaj maybe got some extra attention. Biodiversity perspective now.	prioritized, but in practice species other than Sal and Saaj were often cleared. Biodiversity perspective now.	Biodiversity perspective now.
Management Structure and Forest Division						
Structure	Rotational management carried out in one block per year.	Rotational management carried out in one block per year. If needed, more blocks.	Rotational management carried out in one block per year.	Rotational management carried out in one block per year.	Principally rotational management in one block per year.	Principally rotational management in one block per year.
Blocks	5 blocks.	6 blocks.	5 blocks.	5 blocks.	3 blocks.	6 blocks.
Meeting Structure						
Executive Committee	Meet on monthly basis. 11 members.	Meet at least once a month. 15 members.	Meet on monthly basis. 9 members.	Meet on monthly basis. 13 members.	Meet on monthly basis. 11 members. Call advisors if necessary.	Meet on monthly basis. 11 members.
General Assembly	Held once a year. ≈ 100 % of the hh participate.	Held once a year. ≈ 80 % of the hh participate.	Held once a year. ≈ 80 % of the hh participate.	Held once a year. ≈ 95 % of the hh participate.	Held once a year. ≈ 75 % of the hh participate.	Held once a year. ≈ 70 % of the hh participate.

Forest Products and Dependency						
Timber	≈ 100 % of hh harvest timber between March to April. Outtake is based on application and need of users, and decision made by executive committee. Max. 30 cft per hh/year taken out from forest. Hh pay 30 rps per cft.	≈ 15-20 % hh interested. Collection of timber between November and February. All hh shall participate 2 days. Distribution based on application and need. Timber prize is adjusted to hh wealth ranking (from 0 rps to 125 rps per Bhari[b]).	≈ 100 % of hh have interest in timber. Timber taken out between November and February. Labour is engaged in outtake and timber is sold to users for 450 rps per cft.	≈ 100 % of hh have interest in timber. Timber is taken out between November and February. Distribution is based on application, necessity and priority. One cft cost 400 rps, users can get a maximum of 50 cft.	15 – 20 hh get timber each year. Yearly amount that can be harvested during November to February is based on provisions in OP. Users apply (application fee of 10 rps) for allowance to cut. Decision based on necessity and priority given thereafter. Users who get allowance to cut, get the whole tree. Rps. 35 per cft.	≈ 10 % get timber each year. Users harvest trees they have been allowed to cut during November to February. 50 rps per cft. Can apply for a bigger outtake if specific reasons (max. 15 Bhari[b]).
Firewood	≈ 100 % of hh have interest in firewood. Collection of firewood (alive trees)	≈ 20-30 % hh interested. Collection of firewood (alive trees) only during	≈ 60 % of the hh have interest in firewood. Up to 40 Bhari [b] taken out per hh during	≈ 50 % of the hh have interest in firewood. Firewood is carried by users from	≈50 % hh interested. Only collected at the same time as timber is harvested. Amount	≈ 85 % of the hh have interest in firewood. Collected mainly during

	only during thinning. Collection of dry and dead wood, in addition to during thinning, also during festivals. In special occasions CFUG opens up for collection once a week. Hh carry what they collect themselves. Firewood is taken out for free.	thinning/pruning. All hh shall participate 2 days and wood is distributed equally. Up to 10 Bhari[b] pr. hh is free of cost. Dead branches (dry firewood) can be collected all year around.	thinning. Have an auction where wood is sold to the one who bid most. Dry firewood can be collected all year around. Few hh do collect.	management activities such as bush cleaning and thinning. Allocated trees (old, dead and deformed) are cut and carried against a small sum. Dry wood can be collected all year around. People harvest much during festivals. Up to 20 Bhari [b] is 4 rps. each, and beyond 20 Bhari [b] is 10 rps.	that can be harvested and distributed is decided by the executive committee. Rps 1 per Bhari[b]. No collection of dry firewood during the year. Most users rely on private land for firewood.	thinning/pruning, harvesting and before festivals. 10 rps per Bhari[b]. Maximum outtake is 10 Bhari[b] per hh. Trees useless as timber are taken out as firewood. At times collectively collection of dead and deformed trees. Distributed among those interested. Dead branches cut on Saturdays all year around.
Fodder	≈ 75 % of the hh go for fodder. Fodder from all species can be collected all year around.	≈ 30-35 % hh interested. Fodder from all species can be collected all year around.	≈ 45 % of the hh collect fodder. Big branches and saplings of Sal shall not be cut. Seedlings in dense forest can be cut. Collection of fodder all year around.	≈ 50 % of the hh collect fodder. Fodder can be collected from green trees all year around (branches) as long as they are not cut.	35 ≈ % interested. No collection of seedlings and saplings. Most users rely on private land for fodder collection.	≈ 60 % collect fodder. Seedlings and saplings shall not be cut. Restrictions on cutting Sal and Schima. Other species can be cut Saturday’s all year around.

Ground grass	Ground grass can be collected all year around.	Ground grass can be collected all year around.	Ground grass can be collected all year around.	Ground grass can be collected all year around.	Ground grass can be collected all year around.	Free collection once in a week.
Leaf litter	No collection.	No collection.	No collection.	No collection.	No collection.	No collection.
Local Forest Management						
Guards	No guards per now. Plan to make hh start patrolling forest on rotational basis during dry season.	Guards in forest during dry season. Hh patrol on rotational basis, 6 people at a time.	Users patrol forest on rotational basis. 3 people at a time. Especially focus at Sal during dry season when leaves are fresh.	Users patrol forest on rotational basis during dry season. All hh shall be involved.	"Rotational stick system": Each day during dry season one hh is responsible for guarding the forest. The next day they hand over a stick to another hh that then get the responsibility	A guard from the user group patrol forest during dry season. Payment 4000 rps/month.
Thinning	Carried out on rotational basis. One block per year. All hh help. November to February.	Carried out on rotational basis. One block per year. All hh shall help 2 days, if not they will be fined. November to February.	Carried out on rotational basis. One block per year. November to February.	Carried out on rotational basis, one block per year. Recent years during January. All hh shall participate.	Has not been carried out the last 5-6 years as it is perceived as degrading forest, not improving forest health. When it was rotationally carried out, all hh should help and product was	Thinning has not been carried out the last 5-6 years as it is seen as disadvantageous for forest health. It used to be carried out regularly on rotational basis.

					equally distributed among the hh. 1 rps per Bhari[b]	
Pruning	Carried out on rotational basis. One block per year. All hh help.	Carried out on rotational basis. One block per year. All shall hh help 2 days	Carried out on rotational basis.	Carried out on rotational basis.	Carried out on rotational basis.	Carried out on rotational basis.
Fire-line making	Fire-lines have not been made the last 3 years.	All hh participate 2 days in making fire-lines. REDD$^+$-money used in prevention.	Uses REDD$^+$-money for making of fire-lines.	Fire-lines made during March and April.	Making of fire-lines and working on awareness rising of fire protection.	Fire-lines made during March and April.
External Forest Management						
REDD$^+$-money	Loan without interests to poor families and Dalit for goat- and pig keeping. Supporting biogas-plantations. Improvement of cooking stoves. Thinning activities. Plan to establish pinus-plantation upslope.	Distributed to poor people so that they can buy livestock. 3 biogas-plantations are established, one is under construction. Improving cooking stoves for 150 hh where 35 are REDD$^+$-sponsored, rest sponsored by CFUG-fund.	Planning to invest money for improving the livelihood of poor and Dalit-families. Will also be used in forest management practices.	Livelihood improvement for poor people. Loan without interest for goat keeping. Also spent for management activities, carbon inventories, meetings, snacks in forest management and awareness rising.	Planning to invest money in: poverty reduction by giving loan without interest for goat- and pig-keeping to poor families. Awareness rising on forest conservation and prevention of fire.	Very poor households get loan without interest to establish goat husbandry. Money is also used to pay the salary of forest guards, for fire protection and to buy agricultural tools needed in forest management practices.

DFO-directions	DFO (by February/March 2012) by letter asked the CFUG's to stop cutting of Sal, both alive and dead trees. This results from the present situation at the Terai with heavy illegal cutting of Sal and subsequent degradation.					
Additional Information						
Last fire with impacts	Massive fire 4 years ago. Small fires are easily controlled now. Massive fires were common before CF management.	Massive fire 4 years ago. Since then, no fires. Small fires easily and quickly controlled as people are aware of carbon emissions.	Noticeable, but not massive fire 4 years ago.	Massive fire 4 years ago. Since then, no fires.	No influential fires the recent years.	Massive fire 7 years ago. Recently there was a fire, but it was easily controlled and had only little impact.
Impact of Road Construction in 1982 on Forest	The construction of the road had no specific impact on the forest as most good trees were already cleared and because of the notable distance from the forest to the road.	Establishment of the road had big impacts on the forest because of improved accessibility and transportation.	Big impacts of road establishment on the forest. Timber demand from Gorkha was great because of construction. The easy accessibility and transportation increased timber-outtake.	Big impacts of road on the forest. Much timber was needed in Gorkha and the easy accessibility and transportation possibilities increased outtake.	Big impacts of road on the forest. Much timber was needed in Gorkha and the easy accessibility and transportation possibilities increased outtake.	Do not report big influence. Most trees were already felled at the time of its establishment.
Walking Time from Gorkha to Forest	Approximately 2 hours.	Between 1,5 – 2 hours.	Approximately 1 hour.	Approximately 1 hour.	Approximately 1,5 hour.	30 minutes.
Livestock (% of hh)	≈100 Rate decreasing.	≈40 Rate decreasing.	≈100 Rate decreasing.	≈95 Rate decreasing.	≈75 Rate decreasing.	≈60 Rate decreasing.

Grazing	Restricted.	No restrictions. Few hh take livestock for grazing.	Restricted in principle, but in practice a few hh take goats for grazing.	Restricted.	Restricted. But reported that some take animals to graze.	Restricted.
Rule Breaking	Monetary fine in case of rule breaking. Few cases where fines are given for illegal cutting and grazing.	Monetary fine in case of rule breaking. Few cases as fines are high.	Monetary fine in case of rule breaking. Report some cases where fines for cutting and lopping of Sal have been given.	Monetary fine in case of rule breaking.	Monetary fines have been given in some cases when rules have been broken.	Monetary fines given if rules are broken. Few cases as fines are very high (ex. 1000 rps for cutting Sal).

[1] ICIMOD; ANSAB; FECOFUN (2010).

[2] Operational Plans (Community Forest User Group & District Forest Office 1990-1994).

[3] Data gathered from interviews conducted in 2012.

[4] GIS estimates on map from ICIMOD (2010).

[b] 1 *Bhari* = 50 kg green fuelwood; 25 kg fodder; 20 kg leaf litter; 20 kg grass (Adhikari et al. 2004a).

≈ Indicates *c* % of households interested in various forest products[3]. The estimation is made by CFUG leaders