APPLICATION OF INDIVIDUAL BASED FOREST GAP MODEL FOR SAL FOREST IN NEPAL

DIPAK JNAWALI

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2008**

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Thesis
Entitled

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.....

Mr. Dipak Jnawali
Candidate

.....

Assist. Prof. Raywadee Roachanakanan
Ph.D. (Ecology, Evolution and Systematics)
Major-Advisor

.....

Lect. Kulvadee Kansuntisukmongkol
Ph.D. (Ecology)
Co-Advisor

.....

Prof. Banchong Mahaisavariya
M.D.
Dean
Faculty of Graduate Studies

.....

Assoc. Prof. Sansanee Choowaew
Ph.D. (Environmental Planning)
Chair
Master of Science Programme in Natural Resource Management
Faculty of Environment and Resource Studies

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APPLICATION OF INDIVIDUAL BASED FOREST GAP MODEL FOR SAL FOREST IN NEPAL

was submitted to the Faculty of Graduate Studies, Mahidol University
for the degree of Master of Science (Natural Resource Management)
on
February 14, 2008

.....
Mr. Dipak Jnawali
Candidate

.....
Assist. Prof. Ladawan Puangchit
D.Sc. (Silviculture)
Chair

.....
Assist. Prof. Raywadee Roachanakanan
Ph.D. (Ecology, Evolution and Systematics)
Member

.....
Lect. Kulvadee Kansuntisukmongkol
Ph.D. (Ecology)
Member

.....
Prof. Banchong Mahaisavariya
M.D.
Dean
Faculty of Graduate Studies
Mahidol University

.....
Assist. Prof. Sittiong Dilokwanich
Ph.D. (Human Geography)
Dean
Faculty of Environment and Resource Studies
Mahidol University

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Dipak Jnawali

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DIPAK JNAWALI 4937419 ENRM/M

M.Sc. (NATURAL RESOURCE MANAGEMENT)

THESIS ADVISORS: RAYWADEE ROACHANAKANAN, Ph.D. (ECOLOGY, EVOLUTION AND SYSTEMATICS), KULVADEE KANSUNTISUKMONGKOL, Ph.D. (ECOLOGY)

ABSTRACT

The *Shorea robusta* (sal) forest is prevalent in tropical and subtropical region of South Asia. It is a major forest type in Nepal, mostly dominant in lowland areas of the country. It has high ecological and economic significance because it provides shelter for globally significant mammals and other endangered animals, supplies products for the basic livelihood and economic development, and many other ecological services. Knowledge of the dynamics of sal forest composition is important for long term management, conservation strategy and action planning. There is a knowledge gap in the dynamics of sal forest. Formulating and applying a computer simulation of the forest would contribute to filling this gap. No computer simulation model has yet been developed or applied to this situation. This study therefore applies the individual based computer simulation gap model for sal forest to understand its long term dynamics.

Chitawan National Park, a protected area of sub-tropical low land of Nepal, was selected for the study. A total of 40 ha climax sal forest were measured thorough sample plot method. Basal area and stem density were computed. The KIAMBRAM simulation model, which was originally developed in Australian subtropical rain forest, was chosen for this study. Four major components; growth, birth, kill and chablis of the KIAMBRAM model were selected and most of the parameters were calibrated through literature, expert option and the researcher's experience. Re-parameterized model was run to simulate the stand level structure and composition at different successional stages. Simulated stands were subjected to responses of the local environment to the structure and composition of the tree species. Model simulated results were compared quantitatively and qualitatively with empirical data and literature.

Simulated model results showed higher basal area and similar stem density when compared with existing mature sal forest condition. At the species level, neither basal area nor stem density was matched between the simulation and observation. Model simulated species composition for mature forest was significantly matched with current mature forest composition. Similarly, simulated species composition at the early succession stage also was matched with the literature. Model simulated species composition for mid-successional stage and late-successional stages were satisfactorily matched with the literature. Thus, this study showed that application of individual based gap model has potential in the study of the sal forest dynamics.

This study has laid the foundation of a computer simulation individual based gap model to study the dynamics of the sal forest stand in the context of lowland forest of Nepal. Further research and government emphasis on this aspect is expected to contribute to improving the computer simulation gap model for sal forest dynamics.

KEYWORDS: KIAMBRAM MODEL / *Shorea robusta* FOREST / COMPUTER SIMULATION/ CLIMAX FOREST/ FOREST SUCCESSION/ BASAL AREA / STEM DENSITY

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LIST OF ABBREVIATION

Age_{max}	Maximum age of the tree species that can alive
BA	Basal area
BZ	Buffer zone area of the National Park
CF	Community Forest
CFUG	Community Forest User Group
CHABLIS	Probability of tree fall
CNP	Chitawan National Park
DBH	Diameter at breast height
D_{max}	Maximum diameter of the species that can attained in entire life period
DoF	Department of Forest
DNPWC	Department of National Park and Wildlife Reserve
ha	Hectare (unit of area)
HMGN	His Majesty's Government of Nepal
H_{max}	Maximum height of the species that can attained in entire life period
KIAMBRAM	Name of the forest gap model that was developed and applied in Australian's subtropical vine forest
LUMBER	Harvesting frequency of logging
MPFS	Master Plan for Forestry Sector
NP	National Park
NAWR	National Parks and Wildlife Reserve
SD	Standard deviation
SPSP	Species specific parameters
SISP	Site specific parameters
STRGLE	Plantation parameters (plantation frequency)
VDC	Village development committee

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CHAPTER 1
INTRODUCTION

1.1 Background and justification

Forest degradation and loss of biological diversity is becoming most prominent environment concern at global, regional and local level (Global Environmental Outlook, 2003). Tropical forest of the world is increasingly utilized to meet the demand of the wood product (Shugart et al, 1980; Huth et al, 2004). Most of the countries left limited forest area and demanding appropriate management strategy for long term sustainability. Forest management requires considerable knowledge on forest composition dynamics to make projection of the future (Botkin, 1993). Only the reliable method helps to understand the implications of the assumption, therefore needs formal and quantitative model for forest growth (Botkin, 1993). In forest ecology and management, long-term monitoring is the most accurate method for assessing the knowledge of forest composition dynamics. However, such kinds of monitoring system are either not established or not adequately functioning (Roachanakanan, 2002). Formulating the computer simulation forest prediction models may contribute to resolve knowledge gap issues because these models may have significant for examine, analyze and understand the complexity of the ecosystems and impacts of environmental and anthropogenic consequences on ecosystem. Development of computer simulation forest prediction model in developing countries is very challenging due to lack of long term permanent plot information and lack of human and financial resources (Roachanakanan, 2002). However, gap models have been adapted to many different forest ecosystems (Botkin, 1993; Shugart, 1984; Phipps, 1979; Kellomaki and Vaisanen, 1991) but most of the past researches of application of gap models focused on temperate forest than tropical and subtropical forest. On the other hand, worldwide attention to control the accelerating loss of biodiversity and forest loss in tropical area is raising onward, but

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comparatively, no sufficient researches are focused or available on the attributes of the tropical forest dynamics. Tropical forest of South Asian Countries have significant biological values but these area is under higher pressure because of crosscutting issue of population and poverty. Very few researches are focused about the ecological consequences of forest changes in these regions. Among the different forest ecosystem, *Shorea robusta* (sal) forest is one of the most important but threatening ecosystems in this region.

Sal forest is prevalent in tropical and subtropical region of South Asia distributed on the plain and lower foothills of Himalyas (Gautam and Devoe, 2006), Siwalik hill and river valleys (Jackson, 1994), which covers about 10 million ha in India (Tewari, 1995), 1 million ha in Nepal (HMGN, 1988), 0.11 million ha in Bangladesh (Alam, 1996) and some parts in Bhutan (Gautam and Devoe, 2006). Sal species belongs to the dipterocarpaceae family, most productive, ecologically and economically important for tropics (Kandel and Shrestha, 2001), important resource for commercial and subsistence purpose (Webb and Sah, 2003).

Nepal is small (14.7 million ha) landlocked country therefore forest resource is the most important and second largest natural resource after water for the country. Nepal is facing forest degradation during the last four decades; the forest area has noticeably decreased in quantity and quality due to over exploitation of timber, firewood and other forest product, open grazing and encroachment of the forest area for other land (HMGN, 2001). Statistics of forest of Nepal shows that forest cover in 1964 was 6.4 million ha but currently it remains only 4.27 million ha (29% of the country's total area) (DFRS, 1999). The Terai in Nepal is southern low land, which covers only 23% of the total land area of Nepal where 48% of population lives. Before 1950, forest in Nepal's Terai covers more than 75% of land (Timilsina et al, 2007) and forest was intact (Timilsina et al, 2007; Rautiainen and Suoheimo, 1997). After that time, forest was heavily cut for Malaria eradication, Birta land (large area capture as a private property) of Rana owned families and railway sleepers exported to India (Kandel and Shrestha, 2001). Between 1978 and 1991, about 99,000 ha of sal forest in the Terai area was cleared with an average rate of deforestation of 1.3% per year (DFRS, 1999). Forest land in Terai area (lowland) of Nepal still covers 30%, with roughly half of in protected area. Forest types in southern lowland area of Nepal are

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mostly pure mature sal forest and mixed with other species. Sal species is the most dominating species in Nepal having highest stem volume 28.2% (109.4 million m^3) (DFRS, 1999) and this species alone covers more than 70% of the forest area of the southern Nepal (HMGN, 2001).

Agricultural, livestock and forestry is major livelihood strategy of the rural people (Kandel and Sheretha, 2001) which comprises more than 80% of the population of the country depends on sal forest for subsistence needs (Timilsina et al, 2007). Local people collect fuel-wood, timber fodder, pole, wild vegetable from these forests to fulfill their daily livelihood. Sal forest in Nepal is also important for large mammal such as Tiger and Elephant (Shrestha, 2004) in protected area as well as landscape level conservation in Terai (HMGN, 2004). Sal is economically important and most demanded timber in South Asia having stumpage price 140 US $/m^3$ of round wood in Nepal (Kandel and Sheretha, 2001). Sal forest of Terai belt is ecologically important because it contributes varieties of ecological services such as significant for carbon sinks due to processing larger leaf–surface area (Kandel and Shrestha, 2001). This forest plays the function of the buffer strips protecting the larger and productive agricultural land in the Terai from the land slide and flood. Similarly, the sal forest of Terai belt is most important for recharging the ground water in the Terai and supply of the fertility to the agricultural land (NPC, 1995).

Terai forests are broadly categorized into two management regimes: protected area management system and government managed forest. Five protected areas in lowland of Nepal fall under the protected area management system comprise almost half of the total lowland forest of Nepal (Timilsina, 2005). Forest under the protected area management system is now running in climax stage where composition and structure is changing due to different environment consequences. Rest half of the forests outside the protected area are under governmental management regimes and these forests are focused on protection against illegal cutting. Where open grazing system exists, timbers are allowed to collect from dead, dying and fallen tree according to government rule and regulation, and forest fire is occurring every year. Another major management regime of the forest outside the protected area is community based forest management. Though community forestry program in middle hill of Nepal is successful in participatory management approach, it is unable to speed

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up in Nepal's Terai case because of the problem in handing over the forest to the community (Kandel and Shreshtha, 2001). Local community in lowland of Nepal has initiated to manage their forest as a community forest started from degraded forests and grasslands since beginning of 1990s. Now, more than 100,000 ha forest is being managed by local communities in lowland of Nepal (DoF, 2007).

Local communities are applying different management options to protect their forest. Buffer zone community forest (Forest outside but periphery of the national park, which is formally handed over to the local community as a principle of ecosystem management perspectives) of the protected area are being managed under protected area regimes by local community. Community forests have been changes over the course of the time and local communities have gained knowledge about these changes. Collecting information of forest dynamics change through interaction with local communities is also vital because such study is not carried out yet.

To attempt the grounded body of knowledge of organization and function of sal forest dynamics, application of the forest gap model is vital for the study. Most of this knowledge is unpublished and diffused. It is expected that re-parameterization, then after testing of appropriate computer based model[1] will aid a new avenue for sal forest dynamics which will be a framework for synthesizing information about the attributes of sal forest. The tested model (end product of the study) will also provide an effective tool for projecting the possible ecosystem consequences of observed phenomena in sal forest and for assessing possible consequences of utilizing these forests.

Some researches in past carried out on statistical changes of the sal forest but none of the research is found on mechanistic process based study for the sal forest. Some of the important issues such as, how forest passes different succession stage, what is the driving force for changing the forest, how environmental influences is responding to the forest change should be incorporated in the research to know the ecological process rather than static computation. Gap is the major driving force for the sal forest. The KIAMBRAM gap model may attempt to address the above raised

[1] Model should have developed or applied for similar climatic condition. In this context the KIAMBRAM model looks more appropriate model to apply in subtropical sal forest. Major reason of selecting this model was, this gap model was originally developed in subtropical rain forest of Australia and later it was used and modified for detecting the logging impact in Malaysian dipterocarp forest.

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issues because this model is developed in subtropical forest and also consider the environmental influences including Chabli effect.

1.2 Statement of the problems

Despite their widespread occurrence and importance of sal forest in Nepal, little information exists on ecological aspects of sal forest. Few of past studies is initiated to attempt floristic structure and composition of sal forest inside the protected area (natural forest) in western Nepal (Dinerstein, 1979; Shrestha and Jha, 1997; Timilsina et al, 2007) but they did not incorporate the dynamic growth of sal forest. There is lack of knowledge on floristic structure and composition of matured sal forest inside the protected area of Central Nepal. Past researches mostly attempted to study the issues of sal species (not sal stand), for examples; natural regeneration potential of sal in Nepal (Rautiainen and Suoheimo, 1997), spatial yield model of sal in Nepal (Rautiainen, 1999), but they did not incorporate the gap formation and distance dependent parameters. Although, few researches have been carried out regarding the sal forest growth model (Rautiainen et al, 2000; Behera and Misra, 2006), but their assumption is statistical growth (not incorporated the dynamic growth rate) and these forest growth model are not able to incorporate mechanistic processes (Botkin, 1993; Shugart, 1984).

Moreover, these models do not adequately incorporate the possible disturbance like climate changes, wind throw (Chabli), grazing, kill (mortality), lumber (harvest), birth (new recruits) and growth (expansion on dimension) pattern of every species together. Biological process based model may contribute to know the overall development process closer to reality. But, models that include biological processes and are suitable to support taking decisions about forest management would constitute a great advantage, but unfortunately are still scarce (Mohren et al, 1991). In the case of sal forest, there is no any model developed by incorporating mechanistic process and environmental consequences. The KIAMBRAM gap model consists of mechanistic process and environmental consequences. This model was developed to present the mature forest of subtropical rain forest in Australia and later it was applied to know the effect of different kinds of disturbances in different places.

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Forest managers need a comprehensive scientific understanding of natural stand development process and anthropogenic factors affecting the sal forest when they design the silvicultural regimes, but due to the lack of sufficient research information it could not take place (Gautam and Devoe, 2006). There is lack of availability of information about quantity of tree falling with respect to time and gap formation, birth and growth status after gap formation, and similar to other information.

After introduction of the buffer zone community forestry in the Terai of Nepal, local communities are practicing protection oriented management regimes on their forest. Local communities should have gained some experiences and knowledge on succession development process of the sal forest. In most of the places, initial condition of the handed over community forest was degraded and small patches were formed. Therefore it is the good place for study to collect the secondary successional information.

No any previous researches have been attempted to predict the sal forest dynamics using gap models. Therefore, prediction of sal forest through applying forest gap model with incorporation of different environment consequences is vital to show the clear picture for concerning stakeholders to make appropriate decision for prevention from potential danger. Only the KIAMBRAM model consists of all issues raised in sal forest. Test of the KIAMRAM model will be vital and may overcome the issues raised in sal forest if it is applicable because most of the situation and issues are similar. To accomplish basic work for developing the prediction of gap dynamics model, reliable information about the site specific and species specific physiological parameters are essential (Botkin et al, 1972; Botkin, 1993; Shugart, 1984; Roachanakanan, 2002). Assessment of forest condition inside the National park and protected forest under community based management regimes may contribute to collect the essential information.

Development of new forest gap model for sal forest dynamics is far and beyond the control of this small research because of the lack of time and other resource constraints. In this context, the KIAMBRAM model re-parameterize and test the application to know its applicability (whether it works or not) would be one of the

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pioneering stage for this to establish the foundation for future research of sal forest dynamics.

1.3 Research question

Research question of this study was:

i. To what extent KIAMBRAM model is applicable for prediction of sal forest dynamics.

1.4 Objectives

In accordance with the statement of the problem, objectives of proposed study were:

i. To explore the existing floristic structure and composition of the mature sal forest.
ii. To re-parameterize the KIAMBRAM model with reference to sal forest.
iii. To test the KIAMBRAM model to predict the sal forest dynamics.

1.5 Conceptual framework

This study was aimed to establish foundation of computer simulation gap model for natural sal forest to understand the long term dynamics, which is expected to contribute information for long term conservation and management planning process. Conceptual background of this research is presented in Fig.1.1. Composition, structure and function of the forest can observe only by incorporating the mechanistic process. The mechanistic gap model, which includes growth, birth, kill and Chabli, is appropriate tool for understand the dynamics of long run protected forest. The KIAMBRAM model (which was developed in similar climatic zone) was chosen and it was re-parameterized through literatures, expert consultation and field measurement. Model was used to test sal forest dynamics and it is never ending process (last row in Fig.1.1) because of testing is depends on objective of the study. The process of re-parameterization is repeated until the model provides its desired objectives. In this study, prediction of different successional stage is set for the model objective therefore

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re-parameterization and model testing process is limited up to this objective. In this way, re-parameterized model is the output of the research which will support for future research and development of the sal forest management strategy.

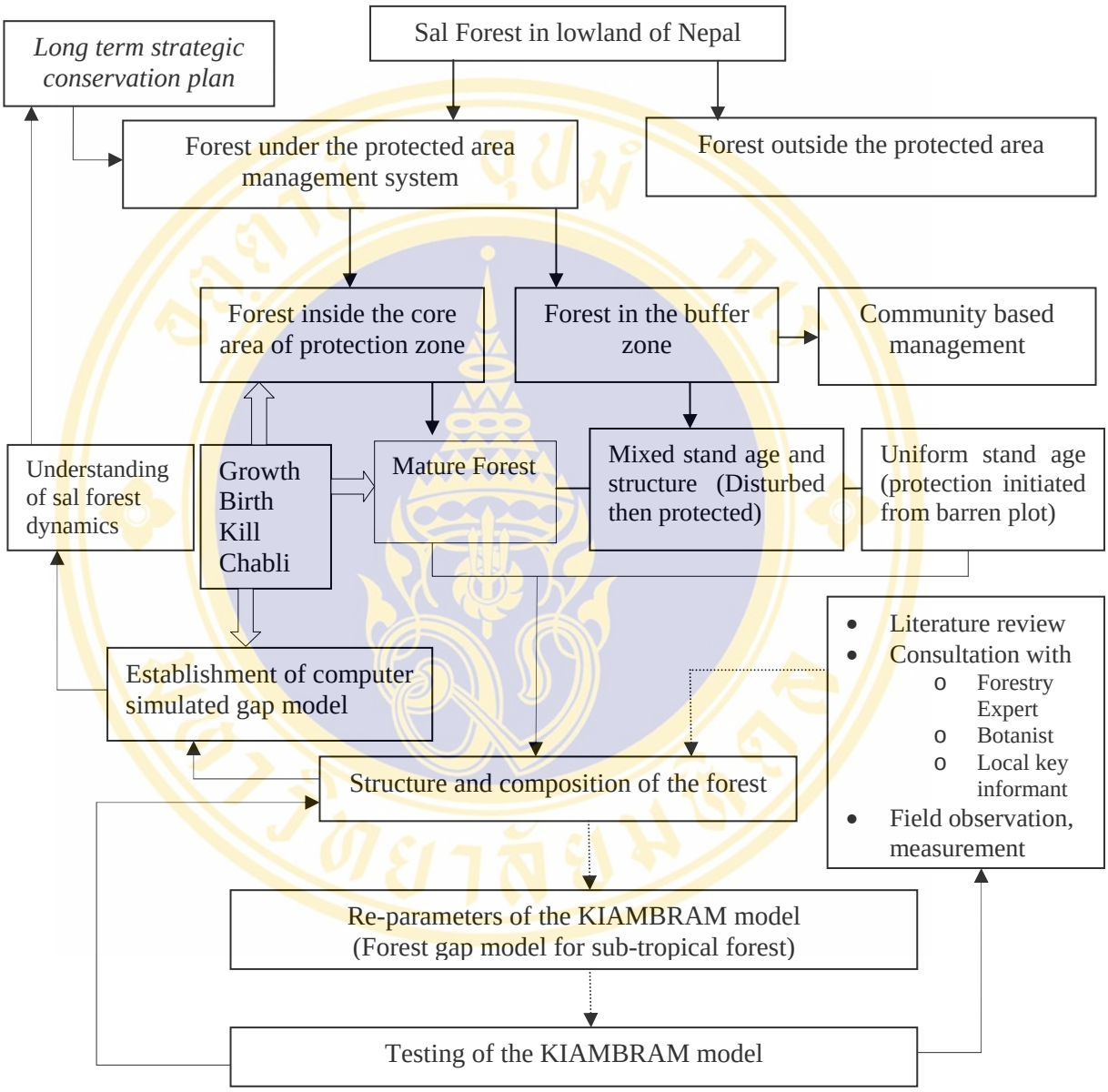

Figure: 1.1: Conceptual framework for the study

1.6 Scope of the study

Sal forest is dominant forest types in Nepal and it covers about 700,000 ha in lowland of southern Nepal. About half of this portion falls in protected area

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management system. Protected area management system is looking for broader level of ecosystem based management that needs connectivity with forest and other subsystems outside the protected area. Forest outside the protected area is moving towards community based management. Therefore, forest has significant linkage. In another perspectives, lowland sal forest in Nepal is connected with 12 protected areas of Nepal and India (HMGN, 2004), and management strategy has been implemented. However, this study incorporate only the protected area from central Nepal but selected forest will almost be similar in climatic, biophysical conditions with the rest of the sal forest of other protected area in lowland of Nepal. Implication of the model to the community based management is high because total numbers of community forestry user groups in Terai of Nepal (in 19 districts) are 957 with 101,917 ha of forest land benefiting 221,705 households (HH) (DoF, 2007) and it is rapidly increasing trend (this data has not included the buffer zone community forest).

This research attempts only tree species but in reality many other species such as species of climbers, herbaceous plants and shrubs are abounding in the forest. Because of lack of physiological and ecological species specific research on sal forest species, this study is limited to look similar research in other places which may not be fit for local area and expert consultation which might also differ than research data. Other limitation of the study is described in Chapter-V.

1.7 Significance of the study

Currently, sal forest is limited only in three countries: India, Nepal and Bangladesh and it is declining in every country. In Nepal, natural regeneration of sal is viable and soil moisture environment is still suitable (Rautiainen and Suoheimo, 1997). In Nepal, sal is mostly abundant in protected areas and these protected areas have globally significant biodiversity (HMGN, 2004). Community based management in degraded forests are recovering and contributing biodiversity conservation and local livelihood gradually. This research is significant in contributing towards achieving biodiversity conservation and sustainable management of the forest for three reasons.

Firstly, this study is applying and developing individual based computer simulation model in protected forest through re-parameterising the available

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appropriate model. Such simulation model could be significant to explore the future possible consequences of sal forest. Knowing the information from model, it can be helpful to choose, modify and adopt the appropriate management regime that supposed to contribute for sustainable management of the forest. Secondly, finding of the research will be useful for understanding the process of changes of forest dynamics and the impacts of the different consequences with the help of running of the model in the computer which could be almost impossible or difficult to study in the real field. Moreover, forests under protection system is shelter and habitat of the large mammals and endanger animals, study will be very useful to know the status of the habitat of the wildlife at the time of interest. Similarly, finding of the study will also be helpful to develop the overall management strategy of the Terai forest of Nepal (Gautam and Devoe, 2006). Moreover, the output of the research is also handed in computer programming and pictorial version which might be useful for educating the people. Forest dynamics gap model is perhaps the first of its kind in Nepal. Hence, it can be useful for further advance research and apply to other types of forest in the country.

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CHAPTER 2
LITERATURE REVIEW

The aim of this chapter is to review the available current literature in order to provide the concrete background and theoretical framework as well as to identify gaps and provide rationale for the study. This study is based on the conceptual context of individual based forest gap dynamics to the growth and development of the plant species under different environmental consequences influences in the sal forest. On behaves of the hypothesis and objectives in chapter one, literatures here are mostly concerning with the concept and process of individual based gap model, sal forest related studies and succession process of sal forest. They are reviewed in the following sections.

2.1 History and concept of forest gap model

The concept of the forest gap or "gap phase" refers to patch[1] in the forest created by the death or fall of a canopy tree. Gap becomes localized for regeneration and subsequence growth. Shugart (1984) stated that 'Following the death of a large tree and its falls, a canopy gap forms. The area below this gap becomes the site of increased regeneration and survival of the trees. The trees grow, the forest builds, the canopy closes, and the gap disappears. Eventually, the now mature forest in the vicinity of the former gap suffers the mortality of a large tree and a new gap is formed and the cycle is repeated'. In the other hand, growth-yield models are used by foresters to assist timber production and evaluate growth and yield of timber species in managing the forests, while gap models are generally developed by ecologists to explore ecological mechanisms and patterns of structure and functional dynamics in natural forest ecosystems (Liu and Ashton, 1995).

[1] Small area usually defined a 100 m^2 (JABOWA model) or 500 m^2 (KIAMBRAM model) circular plot but size of the plot depends on assumption of the model and its structure.

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Forest gap models are a class of individual plant based community models that have been used extensively to study successional dynamics for a wide variety of purposes and applications. Three assumptions generally considered in gap models by researchers: (i) the forest is abstracted as a composite of many small patches of land, where each can have a different age and successional stage, (ii) the leaves of each tree are located at the top of the stem, and (iii) successional processes are described on each patch separately, i.e., there are no interactions between patches.

The computer simulation gap models of forest succession[2], explores the long terms dynamics response of the forest. Shugart (1984) states that gap models are useful to develop the theory and to resolve the problems associated with understanding of forest succession. The first such model was the JABOWA model (Botkin et al, 1972) developed for a forest in New England. Several gap models were subsequently developed (Shugart, 1998) for a wide range of forests; and eventually, for grasslands and savannas. The earlier versions were used for inter-ecosystem comparison (Shugart, 1984) and adhered relatively closely to the original JABOWA formulation. Individual based computer models designed to understand the forest dynamics by following the fates of each individual tree in a forest stand were created initially in the mid-1960s. By the mid of the 1970s, two approaches were fairly distinguished to modeling of the forest dynamics: forest model[3] and tree model[4] (Shugart, 1984). Gap models simulate the changes in a small patch of forest. Shugart and West (1977) found that for gap models, the assumed size of the modeled gap could have a profound effect on the model dynamics; they noted that these effects could be considered to be a "phonological basis for grain-size quantification based on community level interaction". The model projects[5] the annual growth[6] of each individual tree on the

[2] The gradual replacement of one community by another in the development of vegetation towards a "climax" which is culmination stage in plant succession for a given environment (Khanna, 1993).

[3] Model considers the forest (forest stand) as the focal point of the simulation model. State variables of the forest stand (e.g. biomass, volume, index and number of tree per hectare).

[4] The models attempt to simulate the dynamics of forests by computing change in each individual tree in a forest stand.

[5] Calculation by a model of a future state of a system, given the present state (what might be if certain conditions were to hold).

[6] Height and diameter increment of the individual tree.

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patch. The forest gap model also computes death[7] of each tree and the recruitment[8] of each individual tree on the patch.

Gap models are important because of their widespread applications in assessing the effects of environmental change and effect of other disturbances on the forests as a subset of individual based model (IBM)[9]. In dead, gap models are special types of IBM have been applied very wide range of ecosystem and it also interchanges with other IBM when it includes the multi age and multi species. As with other individual-based models, each tree is simulated as an independent entity in gap model. The earliest such models were developed by population ecologists (Holling, 1964; Rohlf and Davenport, 1969) interested in incorporating animal behavior into population models and foresters who were interested in relating tree growth to forest yield[10]. Shugart (2002) stated that most ecologists are interested in variations in individuals (a basis for the theory of evolution and a frequently measured aspect of plants and animals). Increasingly, models that simulate the dynamics of ecological systems by accounting for changes in each of a large number of individuals in the system have been developed and applied in population and ecosystems ecology (Huston et al, 1988; DeAngelis and Waterhouse, 1987).

2.2 Individual based model in forestry

Among the earliest individual-based models in ecology were models of forests based on the growth of the individual trees of the forest stand. Models at that period were developed by forester (especially qualitatively oriented forestry professions) were focused from their inception toward practical issues in production forestry. Focusing on quantitatively degree of change of dimension (size) of the individual trees to better understanding of forest changes has been traditionally practiced in forestry and forest

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[7] The death of the individual tree.

[8] Establishments of the new individuals of defined size (sapling) plant to the existing population. The process may include; sprouting, seed production, seed dispersal, germination, growth of seedling until the young plants are large enough to be through of as trees.

[9] Individual based models are focused at individual level process, these types of model measure process of the dynamics for example, process of individual tree or individual species or individual animals behavior, etc.

[10] Total harvestable quantity available for the given time.

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ecology for over 200 years (Shugart, 2002). In case of IBM, the changes not only focused in sizes of trees, but also it included changes in numbers (from birth and death processes), therefore this led to an interest in simulating the changes in individual trees for understanding forest dynamics. Some of the first IBMs used in ecology were focused only for trees (Shugart, 2002). In forestry practice field, IBMs were focused on solving several general problems involving stand yield tables at earlier phases. But, modern forestry uses stand yield tables as a scientific basis for making decisions about the expected productivity of forest stands under different conditions to plan harvest and thinning schedules. Stand yield tables are calibrated by using data on the performance (height and diameter growth) of individual trees from study plots, with different densities of trees per unit area and grown under different conditions. Some of the European yield tables are based on continuous studies of such plots for as long as 200 years (Shugart, 2003). This is common and very early interest for forester in projecting forest performance under different conditions which could be useful for solving the problems involving the prediction of climate change effects on forests. Therefore, IBMs are very important to contribute in ecological theory through bottom up approach but it should be integrated and coordinated with fundamental ecological theory (Grimm, 1999).

2.3 Structure of gap models

The model structure emphasizes two features: how the individual tree response to prevailing environmental conditions and how the individual tree modifies those environmental conditions (Shugart, 2002). Gap models characterized random processes for the birth and death of trees. To implement the models, one typically averages the responses of 100 or so independent simulated plots. The models can accrue forests by producing ecological succession from bare ground or also can be initiated from forest survey plots to simulate a land from the time it is sampled. The output data is useful for comparisons with forest survey data and references. Botkin (1993) stated that two types of parameters are used in such types of gap models. First, the individual tree parameters (species-specific parameter) for computation of: growth, relation between diameter and height, and other biological and ecological descriptors. Second, site specific parameters for computation of: characterize the interactions

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among trees (for example, shading of light through different levels of the canopy, water availability) or that simulate the overall condition on the plot (depth of leaf litter, soil temperature, etc).

2.3.1 Growth

Tree growth is the major component in the gap model. In the individual based gap model, growth of the tree is generally referred to increment of the diameter and it reflects to volume increment and biomass increment. Increment/growth of the tree species depends on silvicultural characteristic of the species such as shade tolerant level, life historical characteristics of the species such as; maximum diameter, maximum height , maximum age and maximum diameter increment. Botkin (1993), stated that under the optimum condition, if the resources necessity for the tree growth is not limiting factor (*f(environment*[11]*)* in equation 2.1 equals to 1), growth of the tree is directly propositional to the abundance of leaves (which can be measured as a leaf area or leaf weight), and is inversely propositional to the amount of living non-photosynthetic tissue. Since, the quantity of non-photosynthetic tissues is directly proportional to the surface area of simple geometric solid, the surface area of the solid is diameters times' height of the tree.

Therefore, Increment in tree volume

$$\frac{\partial(D^2H)}{\partial t} = R * LA * \left[1 - \left(\frac{DH}{Dmax(i) * Hmax(i)}\right)\right] * f(environment).....(2.1)$$

Where, D = diameter at breast height, H = height of tree,

R = constant, LA = leaf area of tree

$D_{max(i)}$ = maximum known diameter for trees of species i

$H_{max(i)}$ = maximum known height for trees of species i

[11] Primary environmental factors are; availability of sun light, soil moisture, soil mineral and temperature.

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Change/increment in diameter is easy to compute and monitor in real field than tree volume. Therefore equation-2.1 needs to change into diameter form. To develop the equation into diameter form, it needs some other assumptions. The first assumption is that leaf area is proportional to leaf weight (W).

Mathematically, $\text{Leaf area (LA)} = C * D^2 = W \text{ (leaf weight)} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (2.2)$

The functional relationship of height to diameter is

$$H = 137 + b2D - b3D^2 \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (2.3)$$

Where, 137 is the height in centimeters at which DBH is measured.

To find out the value of b2 and b3 in equation 2.3, another assumption is made that tree species reaches its maximum height and maximum diameter at the same time. In that condition, $D = D_{max}$, $H = H_{max}$ and $\frac{\partial (D)}{\partial t} = 0$

Then coefficients b_2 and b_3 for equation 2.3 are:

$$b2 = \frac{2(Hmax - 137)}{Dmax} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (2.4)$$

$$b3 = \frac{(Hmax - 137)}{D^2 max} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (2.5)$$

Here,

multiplying and dividing and by ∂D in left side of equation 2.1, Then,

$$\frac{\partial(D^2H)}{\partial D} * \partial D = R * LA * \left[1 - \left(\frac{DH}{Dmax_{(i)} * Hmax_{(i)}}\right)\right]$$

$$\text{Or } \partial D = \frac{R * LA * \left[1 - \left(\frac{DH}{Dmax(i) * Hmax(i)}\right)\right]}{\frac{\partial(D^2H)}{\partial D}}$$

$$\text{Or } \partial D = \frac{R * CD2 * \left[1 - \left(\frac{DH}{Dmax(i) * Hmax(i)}\right)\right]}{\frac{\partial\{D^2(137 + b2D - b3D2)\}}{\partial D}}$$

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$$\partial D = \frac{G * D\left[1-\left(\frac{DH}{Dmax(i) * Hmax(i)}\right)\right]}{274+3b_2D-4b_3D^2} f(environment)\ldots (2.6)$$

The growth of an individual tree is calculated by using equation 2.6, a species specific equation (because different species have different parameters) to predict the expected diameter increase for each tree under optimal condition.

Growth factor G in equation 2.6 is used in the place of R*C and value of G of the species (i) can be computed by using formula 2.7.

$$G_{\partial Dmax} \cong 5H_{max}\left(\frac{\partial D_{max}}{D_{max}}\right).....(2.7)$$

The equation-2.7 is more realistic than equation-2.8 for estimating the G (Botkin, 1993). Diameter increment of the tree for given time can be computed (using equation 2.6 and substituting G value from 2.7) by knowing the values of: current diameter (D) of the tree, maximum diameter (D_{max}) of the tree species, maximum height (H_{max}) of the species, maximum diameter increment (∂D_{max}) of the species.

Also, G can be computed by,

$$G = \left(\frac{4Hmax}{Agemax}\right)\left\{\begin{array}{l}\ln(2(Dmax-1)+\frac{\alpha}{2}\ln\left(\frac{\frac{9}{4}+\frac{\alpha}{2}}{4D^2max+2\alpha Dmax-\alpha}\right) \\ -\frac{\alpha+\frac{\alpha^2}{2}}{\sqrt{\alpha^2+4a}}\ln\left\{\frac{(3+\alpha-\sqrt{(\alpha^2+4\alpha)})(4D_{max}+\alpha+\sqrt{\alpha^2+4\alpha})}{(3+\alpha+\sqrt{(\alpha^2+4\alpha)})(4D_{max}+\alpha-\sqrt{\alpha^2+4\alpha})}\right\}\end{array}\right\}.....(2.8)$$

Where, $\alpha = 1-\frac{137}{H_{max}}$

Based in this formula, diameter increment of the tree for given time can be computed by knowing value of: current diameter (D) of the tree, maximum diameter (D_{max}) of the tree species, maximum height (H_{max}) of the species and maximum age (Age_{max}) of the species.

Incorporation of above formula in the gap model shows that the principal advantage of formulation of gap model could be obtained from available ecological

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descriptions and silviculturea l characteristics/silvics[12] of tree species (Bodkin et al, 1972). G value in the model is chosen in such a way that a tree reached two-thirds its maximum size (diameter) at one-half its maximum age (Botkin, 1993). This is the third assumption in the optimum growth equation and in the model.

In the growth phenomenon, trees affects each other directly in the local neighborhoods basically through making shade (light competition) and abstracting the more nutrient from the soil (competition for soil nitrogen). In the model, environmental condition at a site[13] changes over time at different rates. Soil fertility, expressed in terms of soil nitrogen content changes the most slowly, soil moisture content changes rapidly and affects rain fall and evaporation and light varies many temporal scales are some environmental factors affects the tree growth (Shugart, 1984; Botkin, 1993). Therefore, to make clear conceptual idea about the influences of the environment on an individual tree growth, study of the environment response function is important.

Function of environment on individual tree growth

Environment response function {f (e) of equation-2.6} is expressed as:

$$f(\text{environment}) = f_i(AL)^* S(BAR) \quad \ldots\ldots\ldots\

Mathematically, availability of light at any height (h) above the ground is expressed as:

$$AL(h) = AL_o \exp\{-k \int_h^{\infty} LA(h')dh'\} \quad \text{.....(2.10) (Botkin, 1993)}$$

Where, AL_o = light available above the forest,

h = the depth measured down into the forest,

LA (h') = "shading leaf area" or "shading leaf weight" (leaf of the tree above the h), and

k = light extinction coefficient (constant).

Nature of distribution of leaves with height varies from species to species and roughly correlates with the successional stage characteristics of a species. For example, shade-tolerant species have leaves that extend from top of the tree to near the ground, whereas the lowest leaves on a shade-intolerant species typically high up (Botkin, 1993). This affects in the physiological process of the plant that in low level of light deep in the canopy, the photosynthetic response of a leaf of a shade-tolerant species can be sufficient for this occur, whereas it is not sufficient for the leaf of a shade – intolerant species. For the light response component in the model following assumptions are made (Refer: section 2.1).

- All of the leaf weight is concentrated at a point at the top of a tree.
- All of the leaves of one tree shade any shorter tree.
- None of the leaves of any shorter tree shade any leaf of a taller tree.

$$f(AL)L = Al\{1 - e^{(A2*AL-A3)}\} \quad \text{.....2.11.a (Shugart et al, 1980)}$$

Where, A_1, A_2, and A_3, are empirically derived constants, AL is the light available to a tree, and L is the shade tolerant class (L=1 for tolerant, 2 for intermediate and 3 for intolerant).

Therefore, $f(AL)1 = \{1 - e^{-4.64\ (AL - 0.05)}\}$ ....2.11.b (for shade tolerant)

$$f(AL)3 = 2.24\{1 - e^{-1.136\ (AL - 0.08)}\} \quad \text{.....2.11.c (for shade intolerant)}$$

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A shade-tolerant species is comparatively efficient in using light when little is available, but it becomes light saturated at comparatively low light intensities. A shade-intolerant species has comparatively low growth rates under low light conditions but responds more rapidly to increases in light and reaches saturation at a much higher light intensity than a shade-tolerant species .

Function of the maximum basal area S(BAR) in equation 2.9 is expressed as:

$$S(BAR) = 1 - BAR/SOILQ \quad \text{.....(2.12)}$$

Where, S(BAR) = ratio of the unoccupied basal area,

BAR = the total basal area on the plot, and

SOILQ = maximum allowed basal area

In the model, maximum basal area component will represent the site index (Botkin, 1993) i.e. upper limit of the trees that could be supported on sites. Model can be run using and testing different value of SOILQ and its effect.

2.3.2 Regeneration

Regeneration is similar important phenomenon like growth in the gap dynamics. The term regeneration is defined as, the individual or group of plant reach some minimum age or size at which they are included in the population counts, they may be originated with birth or with requirement. Regeneration in the model is stochastic process. The complexity of the regeneration process in trees and its stochastic nature makes it nearly impossible to predict the success of an individual tree seedling. The regeneration of the mature tree can be divided into several stages; the production of viable seeds by a tree, the dispersal of the seeds, germination of the seeds, survival of the seedlings, and recruitment of the sapling (reaches at the defined size). To simplify this complexity, model assumed that there is an abundant of the seed trees nearby forest area for all the species of trees that can grow under the current climate and soil conditions. Most gap models are designed to treat regeneration in trees from a pragmatic view that the factors influencing the establishment of seedlings can be usefully grouped in broad classes also the reason of facilitation [14] . Tree

[14] Facilitation: one species prepares the way for the second, and that without the presence of the first the second could never appear. The occurrence of the first species is a necessary condition for the occurrence of the second.

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establishment and regeneration are largely stochastic, with maximum potential establishment rates constrained by the same environmental factors that modify tree growth. Each simulation year, a pool of potential recruits is filtered through the environmental context of the plot, and a few new individuals are established. Malanson (1996) has applied a spatially explicit gap model to investigate the effects of dispersal probability on forest dynamics. He found that relatively rare instances of a given species of tree entering the patch and establishing itself could have profound influences on the forest dynamics and diversity. Unfortunately, such events are also very difficult to observe, much less quantifiable, under field conditions.

2.3.3 Mortality

The death (mortality) of individuals is modeled as a stochastic process and it controls the population. Most gap models have two components of mortality: age related and stress induced. Shugart (1984) mentioned that the age-related component in the model applies equally to all individuals of a species and depends on the maximum expected longevity for the species. For example; the species whose age is 300 years, yielding an annual survivorship rate of around 1–2%. The probability of mortality of each individual tree is determined as a stochastic function. Each tree is assumed to have an intrinsic mortality rate such that, under normal conditions, 1% of the individuals in a cohort could be expected to live long enough to attain their maximum height and diameter (Botkin, 1993). The mortality of plants, in general and certainty of trees is relatively poorly known aspect in plant ecology and the formulations in many of the gap models reflect the state of knowledge. The tendency in most of the existing gap models has relatively used straightforward descriptions of mortality in the anticipation of additional information. Trees that are growing slowly have an increased probability of death. In the earlier gap models, trees with a minimum diameter increment of 1 mm per year are subjected to additional mortality that has the effect of allowing only a 1% chance that they will survive 10 years (Botkin et al, 1972). In more recent gap models, stress is defined with respect to a minimal diameter increment (typically 10% of optimum growth for a given size of tree) and individuals failing to meet this minimal condition are subjected to an elevated mortality rate.

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Mathematically, $P_m = 1 - \exp(\frac{-4.605}{AGEMX})$ .....2.13 (Shugart et al, 1980)

Where, Age_{max} is the age at which one would expect 1% of a cohort to be alive.

The trees whose rate of growth is suppressed due to shading or other factors, to the point that their diameter increment is less than 1 mm per year, are subjected to additional mortality, Ps = 0.368 (Shugart et al, 1980).

Most gap models place the vast majority of their emphasis, in terms of process detail, computer code, and validation effort, on tree growth. A model component that has received little critical attention is the simulation of plant death (i.e., mortality), which is strikingly similar across nearly all gap models (Shugart, 1998)

2.4 History and changing trend of individual based forest gap models

Stand dynamics are controlled by the creation of gaps due to single or multiple over story-tree mortality in that forest where large scale disturbance are rare. Within these openings, newly established seedlings or advance regeneration will be recruited to the canopy. Gap dynamics are the important driving force that maintains the tropical diversity (Young and Hubbell, 1991). A gap model has been an important tool in understating the dynamics of the forest for long times. Gap models were introduced over 30 years ago to examine the dynamics of forest vegetation structure and species composition based on plant population dynamics. “Individual based gap models basically focus: simulate the birth, growth, and death of individual trees within a small, homogenous forest gap; and use light, stratified vertically through the forest canopy, as the primary resource for which individual stems compete” (Seagle and Liang, 2001). Knowledge on plant physiology is very important to understand the gap dynamics (Reynolds et al, 2001). In this way, Shugart et al (1980) incorporated the gap process in the KIAMBRAM model using concept of Chabli.

Gap models are intended to develop to understand the ecological mechanism and patterns of structure and functional dynamics in natural forest ecosystems over a long period of time (Liu and Ashton, 1995; Kolstrom, 1998). The gap model includes process based approaches that account for competition as well as species-specific life history characteristics (Roachanakanan, 2002). In individual based model, each individual tree is simulated as an independent entity. Gap models are typical individual

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based model and their process in the different sites are different due to variation of disturbances (Shugart and Smith, 1996).

Development of the gap model for tropical forest is challenging because of two reasons: First, data related to long term permanent plots are not easily available in tropical area because of most of the previous researches have been conducted in temperate and boreal regions. Second, most of the tropical forest falls on developing countries and they do not have sufficient resource and manpower to establish the permanent plots. On the other hand, tropical forests are more complicated and diverse than temperate forest (Roachanakanan, 2002).

The JABOWA model (version first) is the first gap model developed in 1972 by Botkin et al (1972) for northern hardwood temperate forest in USA. This model is process oriented based interacts individuals plants. Latter the JABOWA-II model is came out consisted of 40 species. Three subroutines: growth (increment), birth (recuitment) and mortality are incorporated in this version. The plot size is used as a name of SITE 100 m^2 in the model which is quite small for large trees.

The FORET model originally derived from the JABOWA model by Shugart and West (1977) which simulated 33 tree species of deciduous forest of USA. They added additional two subroutines: seedling requirement and vegetative reproduction part. The model is used 1/12 square meter circular simulated plot. The KIAMBRAM model was developed by Shugart et al (1980) by taking the FORET model as dynamics of 125 species in sub-tropical rainforest (details of the KIAMBRAM model is described in Section 2.3.1).

The FORICO model (Doyle, 1982) is a gap model derived from the FORET model consists of 36 species of lower mountain rain forest. The main variable of the model simulation is: presence or absent of the seed tree in the plot, and maximum and minimum temperature available. Data were used 25 years permanent plots. Light, space and nutrients were considered the limiting factor for the growth of the stand.

The OUTENIQUA (Daalen and Shugart, 1989) model is gap model that includes the 28 species found on the study site, developed from the KIAMBRAM model for mixed evergreen forest of South Africa with minimal calibration. This model simulates birth, diameter growth, and death of the mature tree and excludes the harvesting and LUMBER subroutine and the STRGLE subroutine. In this model the

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plot size is considered 400 m^2 area. The model consists one additional subroutine, i.e. SPROUT than KIAMBRAM model for allowing re-sprouters to sprout with the average DBH of 2.0 cm. Growth factor G is calculated from the known maximum diameter increment using formula of Botkin et al (1972). In this model following parameters are similar with KIAMBRAM model: nature of shade tolerant (three levels), seed phenology (two levels), seed longevity (four levels) and SWITCHES 1 to 6 (1-3 seed dispersal, 4-5 types of soil for establishment of seedlings, and 6 is STRGLE. Four additional SPSP for each species; (1) FELL for species re-sprouting ability when fells, (2) SPRT for re-sprouting ability when the tree is fallen (three levels), (3) DEC for deciduousness (three levels), and (4) SEED for the amount of viable seed production (three levels) are incorporated in this model. The chablies probabilities are set 0.006 and less than 0.25 mm/yr diameter increment is subjected to additional mortality in this model.

The FORMAL model is the first application of forest gap model derived from JABOWA- FORET model to study the logging techniques in tropical dipterocarp rain forest in Malaysia (Kurpick et al, 1997). This model has several modifications through grouping the species which lays similar functional characteristics for computation of growth, recruitment, light respondent functions, tree geometric function, and logging practices. In this model, tropical rainforest species are grouped into four different categories according to their potential height and shade- intolerant demands. In their classification, group one includes the shade tolerance species with mature height 36 m, group 2 represents smaller dipterocarp species (height between 28 m and 36 m), group 3 represents for pioneer tree species with typical maximum heights between 15 m and 28 m, and group 4 includes small shade intolerant pioneer tree species. In this model, light extinction coefficient (k) is used 0.7 which is realistic for Malaysian tropical rain forest (Kurpick et al, 1997). They used 1/12 ha plot size for simulation same as the KIAMBRAM model. In this model, no temperature and drought effects are taken into account. They also excluded the environmental factor of crowd competition (soil) on their modification. The growth factor (G) and Age_{max} are computed from maximum diameter increment equation (2.8). Mortality is calculated as in the JABOWA-FOREST model. Logging procedure is developed by using same as the KIAMBRAM model (Shugart et al, 1980). Application for investigation of various logging

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techniques and their influence on the forest composition and sustainability were the main goal of development of the FORMAL model.

The FORMIND model (Kohler and Huth, 1998) derived from the FORMIX-3 model is the combination of growth model, gap model and the JABOWA- FORET model applied in Malaysian tropical rain forest. The simulation plot is considered an area of 400 m^2. A total of 436 tree species were categorized into 22 different functional groups on the basis of diameter growth characteristics and light demand. The functional groups further categorized into five species groups by using the potential height as a criterion named as cohort. Most of the parametric values of five functional groups in this model are used from the FORMIX-3 model. This model concluded that more precise group classification is necessary for reasonable results.

2.5 How does gap models works?

Forest gap models make precise predictions of numbers and sizes of trees of simulated plot (Strasser, 1992). Many authors argued that gap models are more general and realistic than precision (Prentice and Helmisaari, 1991; Strasser, 1992; Botkin, 1993; Botkin 1981; Liu and Ashton, 1995; Bugmann et al, 1996). Forests are intrinsically quite variable and gap model of the dynamics needs not be more precise with its realities. Gap models are process based rather than the quantitative outputs therefore they are flexible to adjust additional parameters whenever they are desired necessary. Some researchers have also found that gap models are not only general and realistic but they also have reasonably accuracy (Roachanakanan, 2002). Therefore, gap models may have been used to accurately predict the course of succession in many different types of forest and represent an efficient method for modeling competition for light (Urban and Shugart, 1992).

Most of the gap models in tropical and sub-tropical forest also are developed from the JABOWA-FORET model. Major difference between the JABOWA model and other above described five models (Section 2.4) is that these models do not consider the temperature and water stress parameters in the rain forest model. Therefore, only one environmental factor (light competition) is sufficient to simulate the model results. According to Bugmann et al (1996), all forest gap models can show the good result in the stand level (e.g. total biomass) but there will be poor

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performance at sub stand level (e.g. size and age distribution). Among the six described gap models, the FORMAL, FORICO, and QUTENIQUA rainforest gap models are capable of computing the simulated total basal area, stem density, diameter class distribution within the significant ranges of observed values, hence these models can satisfy the stand and sub-stand level information (Roachanakanan, 2002). Among these models, only the FORICO model discussed about the species composition (Doyle, 1982).

2.6 Application of the KIAMBRAM model in tropical and subtropical forest

2.6.1 Concept and approaches

The KIAMBRAM model is developed by Shugart et al (1980) for complex sub tropical rainforest in Australia. The model is based on the JABOWA–FORET model. The details of content and characteristic of this model are: simulation of gap size is 1/20 ha (500 m^2), assumption of forest is intact and sufficient seed source, number of species is 125, the inclusion of strangling trees, the inclusion of details aspects of tree establishment (e.g. seed dispersal, seed phenology, seed longevity and seedling establishment). In addition, this model also incorporated the three other subroutines CHABLI, STRGLE and LUMBER. CHABLI subroutine is simply the tree fall but in the model it accounts the effect of tree fall on light level and mortality. STRGLE subroutine in the model accounts the planted tree and sometimes trees go up to the dominant level. LUMBER subroutine in the model accounts impact of harvesting. The model is developing in the different stages: first the model of the single tree, then of set of trees competing in constant environment, then of a set of trees of different species competing in an environment that could be varied (Botkin, 1993). The KIAMBRAM model consists of two main types of model parameters: species specific parameters (SPSPs) and site specific parameters (SISPs). SPSPs explain the important characteristics of each species, whereas SISPs explain site dynamics such as environmental conditions for light and crowd competitions. Following sections will describe details parameter of the SPSPs and SISPs of the KIAMBRAM model.

SPSPs are set to compute the GROW, BIRTH and KILL subroutines in the KIAMBRAM model. In the GROW subroutine: major four parameters: maximum

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diameter (D_{max}), maximum height (H_{max}), growth factor (G) and shade tolerance level (TOL) (Shugart et al,1980 used tolerant, intermediate and intolerant) are incorporated. Similarly, five different parameters: seed phenology (p1) (Shugart et al, 1980 used regular (every year) and irregular (after three year), seed longevity (p2) (Shugart et al, 1980 used four category; 1=up to 6 weeks, 2=1.5 to 3 months, 3=3 months to 1 year, and 4=more than 1 year), seed dispersal (SWITCH 1 to 3) (Shugart et al, 1980 used three categories: bird, wind and gravity), seedling establishment (SWITCH 4 to 5) (Shugart et al, 1980 used mineral soil and raised soil), strangler establishment (SWITCH 6) are included in BIRTH subroutine. Subroutine KILL consists of only single parameter Age_{max} in the KIAMBRAM model.

SISPs in KIAMRAM model also set in relation with GROW, BIRTH and KILL. Three parameters: light extinction coefficient (k) (Shugart et al, 1980 used k=0.375), maximum basal area (SOILQ) (Shugart et al, 1980 used SOILQ=160 m^2/ha) and plot size (Shugart et al, 1980 used plot size 1/12 ha) are incorporated in GROW subroutine. Two parameters are considered in BIRTH subroutine: normal condition (Shugart et al, 1980 used requirement per plot as 1-20), and Chabli condition and beginning of the simulation (Shugart et al, 1980 used requirement per plot as 1-600). Three parametric conditions are used in KILL subroutine: mortality increase when diameter increment decrease is less than 1 mm/year (suppression) continuing for 10 years, event of Chablis (Shugart et al, 1980 used chances of uniform random variables with probability 0.50-0.75), and timber operation (Shugart et al, 1980 used increases probability 0.30 due to timber operation). CHABLI subroutine consists of parameter probability of tree fall (Shugart et al, 1980 used tree fall probability 0.003 per year). STRGLE subroutine is explains frequency of plantation parameter in the model (Shugart et al, 1980 used plantation routine is 1 in 20 year). LUMBER subroutine defines harvesting frequency parameter in model (Shugart et al, 1980 used 30 years logging cycle).

When the seedling reached certain age or size, then it is recognized in the new or population counts, which could be entered either from regeneration or from vegetative part from plantation. Recruitment of seedling depends on many different factors such as: presence of seed trees, distribution of the seed tree (evenly or in patches), frequency of good seed year, durability of the seed moisture content,

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characteristics of the plants; for example some plants are regards to germination in dead and heavily decayed log. Seeds fallen on the leaf litter or the open ground of same species may stay without germination. Most of newly sprouted and germinated seedling will survive for only short time period (Botkin, 1993). It indicates sapling requirement is dynamics and complex process, therefore simple calculation is not sufficient to gain accuracy and realism. Only the models can incorporate these kinds of issues. The summary of the KIAMBRAM model structure is given in Table 2.1 and the equations used in the KIAMBRAM model is given in Table 2.2.

Table 2.1: Subroutine and symbol used in the KIAMBRAM model

Symbol used in model	Subroutine		Description
Dmax	GROW		**Maximum diameter** of the tree that tree can achieve in the whole life span.
Hmax	GROW		**Maximum height** of the tree that tree can achieve in the whole life span.
Agemax	GROW and KILL		**Maximum age** of the tree that tree can alive is computed from Dmax , Hmax and G.
G	GROW		Growth factor derived from Dmax, Hmax and Agemax or maximum value of ∂diameter increment
Tol	GROW		**Shade tolerance level:**1=Shade tolerance, 2=Intermediate and 3=Shade intolerance
P1	BIRTH		**Seed phenology:** 1=Regular (Species having a seed source each year), 2=Irregular (Species having a seed source one time during three year).
P2	BIRTH		**Seed longevity:** 1 (<1.5 months), 2 (>1.5 months to 3.0 months), 3 (>3 months to 1 year) and 4 (>1 year).
SWITCH-1	BIRTH	Seed dispersal	**Dispersal by bird:** Flag –TRUE if species needs bird for seed dispersal.
SWITCH-2	BIRTH		**Dispersal by wind:** Flag –TRUE if species needs wind for seed dispersal.
SWITCH-3	BIRTH		**Dispersal by gravity:** Flag –TRUE if species needs gravity for seed dispersal.
SWITCH-4	BIRTH	Soil required for new plant establishment	Flag –TRUE if species needs mineral soil for establishment
SWITCH-5	BIRTH		Flag –TRUE if species needs raised soil for establishment.
SWITCH-6	STRGLE		Separate strangler and host species.

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Table 2.2: Equations used in the KIAMBRAM model

Process **GROW-subroutine**	Related equation	Equation no.
Growth of the tree	Volume growth $\frac{\partial(D^2H)}{\partial t} = R * LA * \left[1-(\frac{DH}{D\max H\max}\right]$ Where , Leaf area (LA) $\approx C * D^2$	1
	Diameter growth $\frac{\partial D}{\partial t} = \frac{\{GD(1-\frac{DH}{Dmax\ Hmax})\}}{(274+3b_2D-4b_3D^2)}$	1.1
	$\frac{\partial D}{\partial t} = \frac{\{GD(1-\frac{DH}{Dmax\ Hmax})\}*r(AL)*S(BAR)}{(274+3b_2D-4b_3D^2)}$	1.2
Growth Factor	$G_{Agemax} = \frac{4H_{max}}{Age\max}$	2
	$\left\{\ln(2(D_{max}-1)+\frac{\alpha}{2}\ln(\frac{\frac{9}{4}+\frac{\alpha}{2}}{4D^2_{max}+2\alpha D_{max}-\alpha}) - \frac{\alpha+\frac{\alpha^2}{2}}{\sqrt{\alpha^2+4a}}\ln\left\{\frac{(3+\alpha-\sqrt{(\alpha^2+4\alpha)})(4D_{max}+\alpha+\sqrt{\alpha^2+4\alpha})}{(3+\alpha+\sqrt{(\alpha^2+4\alpha)})(4D_{max}+\alpha-\sqrt{\alpha^2+4\alpha})}\right\}\right.$ Where $\alpha = 1-\frac{137}{H_{max}}$	
	$G_{\partial Dmax} \cong 5H_{max}(\frac{\partial D_{max}}{D_{max}})$	2.1
Leaf area (LA)	$LA = 11.4W_L^{0.900}$ Where value of W_L can be computed using other three regression equations: $\frac{1}{W_L} = \frac{1}{0.124W_S^{0.794}} + \frac{1}{125}$, $W_S = 0.313\ (D^2H)_L^{0.9733}$ and $W_B = 0.316\ W_s^{0.1.070}$	3 3.1, 3.2 and 3.3

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Table 2.2 Equations used in the KIAMBRAM model (cont.)

Process	Related equation	Equation no.
GROW-subroutine		
Light competition	$Q(h) = Q_o \exp\{-k\int_h^{\infty} LAI(h')dh'\}$	4
	$AL = PHI * \exp\{-k * LAI\}$	4.1
	r (AL) = 1-exp [-4.64 (AL- 0.00766)], for TOL =1 r (AL) = 0.95 [1-exp (-1.136 (AL- 0.04363))], for TOL =3	4.2
Crowd competition	S (BAR) = 1- $\frac{BAR}{SOILQ}$	5
KILL - Subroutine		
Intrinsic mortality	$P_m = 1 - \exp(\frac{-4.605}{AGEMX})$	6
Other relevant formula used in the model		
Relation between height and diameter of the tree	$H = 137 + b_2 D - b_3 D^2$, where b_2 and b_3 are the regression coefficients and their values are: $b_2 = \frac{2(H\max - 137)}{D\max}$ and $b_3 = \frac{(H\max - 137)}{D^2\max}$	7, 7.1 and 7.2

Where, D: diameter of the tree at breast height (cm); H: height of tree (cm); R: a growth rate constant; LA: Leaf area of a tree (m^2); D_{max}: maximum diameter of the species (cm) that can attain under the optimum condition; H_{max}: maximum height of the species (cm) that can attain under the optimum condition; C: a constant; G; Growth factor of the species for optimum condition and equals to RC; r(AL): an index of the light competition (no unit), S(BAR): an index of crowd competition (no unit); Age_{max}: the age in the years that a tree growing under optimum conditions, should attain its maximum height; ∂D_{max}: maximum observed diameter increment (cm/yr); Ws: stem dry weight (kg); W_B: branch dry weight (kg); W_L: leaf dry weight (kg); Q (h): Radiation at a height h; Q_o: Incident radiation; k; light extinction coefficient (unit less); LAI total leaf leaf area of all taller trees above height h divided by the plot size (m^2/m^2); AL: available light; PHI: total incident radiation which the plot can carry under the optimal condition (unit less); p_m: probability of intrinsic tree mortality.

(Source: Roachanakanan, 2002)

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2.6.2 Procedure of re-parameterization of the KIAMBRAM model

Re-parameterization of the model is essential to bring more accuracy and increase its wider applicability. But it is difficult because of lack of sufficient research data and difficult to understand the reason of different assumption. For example, most of the gap models accounted seedlings at approximately 2.5 cm diameter at breast height (DBH) (Seagle and Liang, 2001) but Busing and Clebsch (1987) used 1.3 cm in Southern Appalachian spruce-fir forests. In this model gap is creates by Chablis. Probability of CHABLI subroutine is set 0.003. The value of k is ranges between 0.5 to 0.8 (Holbrook and Lund (1995), Roachanakanan (2002), this values ranges 0.6 to 0.7 in tropical rain forest (Kira, 1978; Odum, 1970) but Shugart et al, 1980 used 0.375 which is out of the range of rain forest due to adjust the diameter frequency (Roachanakanan, 2002). Similar kinds of many contradictory values and information are found in case of site specific information. It is also difficult to find the species specific values of different species because of lack of documentation and research on such topics. Diversified tools and techniques such as search, collection, analysis, projection, interaction and verification is necessary to accomplish this task. Therefore this is not a simple computation but rather analytic and creative.

2.6.3 Test of the KIAMBRAM model

Testing of the model simply refers to get some observation, run the model, and observe it whether the projection are the same as observation. In cases of model testing, most important question arises on what variables are likely to test? In forestry, stand density and basal area are common variables that forester want to test (Botkin, 1993). Botkin (1993) further stated that another important issues for model testing is, collection of adequate data that is always difficult in real situation. If the model output and real situation are significantly closed with desired objective of study, model gains validity. Then after, model can use for the desired purpose.

2.7 Ecological and physiological process of sal forest

Subtropical lowlands affected by monsoonal climatic regimes typically support seasonal broad-leaved forest (Wesche, 1997). In Nepal's lowland, such types of forest

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is dominated and widely known as sal forest (Webb and Shah, 2003). Sal forest generally ranges between 75-95 degree E longitude and 20-32 degree N latitude. Sal is dominant in its stand (Champion and Osmaston, 1962). Satiation (1972) argued that sal forest as species- poor. Number of species abundances, stem density and basal area are the common major three state variable parameters to know the any kinds of Forest stand status; therefore these three parameters are presented to make the conceptual idea about the issue of concerned. In term of stem density, Pandey and Shukla (2003) found 408 trees/ha in Gorakhpur India, Rautiainen (1999) found 152–264 trees/ha in pure, >80 year old sal forest in the Bhabar–Terai zone of Nepal; Webb and Sah (2003) found 607 in natural forest and 857 in succession forest, and Shrestha and Jha (1997) in Bardiya national park found 348 trees/ ha. Similarly, basal area of the sal forest in Gorakhpur India was recorded 96.4 m^2/ha, Shrestha and Jha (1997) found 36 m^2/ha in Bardiya national park of Nepal, Singh et al (1995) found 16.0-61.1 m^2/ha in Corbett National Park, India.

Study of the succession stages of the sal forest is also very important in the gap modeling process. According to Pandey and Shukla (2003) in Gorakhpur of India, *Shorea robusta* was the most frequent species in sal forest. After *S. robusta*, the next most frequent species were *Mallotus philippensis* and *Ichnocarpus frutescens*, followed by *Clerodendrum infortunatum* and *Desmodium gangeticum*. The species which showed over 60% occurrence were *Schleichera oleosa*, *Holarrhena antidysenterica* and *Flacourtia indica* among trees, *Moghania bracteata*, *M. chappar*, *M. lineate*.

In case of primary succession, those areas where no vegetation was bear before. In countries like India and Nepal, such soils can be new alluvial deposits, sand dunes, land slips. As the soil condition is very poor at the very beginning condition, number of species as this stage is fewer, but as the condition improves, their number increases. The rate of succession is generally except in the favorable localities. The early stages of the succession are generally easily recognized as they are generally uniform but in the latter stages, great divergence is noticeable due to moisture and soil condition and it becomes difficult to identify and correlate them. Table 2.3 shows the primary succession of the sal forest in riverine alluvium soil.

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Table 2.3: Succession stage of sal forest (an example of riverine alluvium soil)

Succession stages	Species	Life span	Remarks
1-Pre- stages	*Saccharum spontaneum, Tamarix dioica*	NA	Grass species
2-Early successional stage	*Acacia catechu, Dalbergia sisoo*	NA	
3-Mid successional stage	*Acacia catechu, Dalbergia sisoo Holoptelia sp. Adina cordifolia, Albizzia procera*	NA	*Acacia catechu* and *Dalbergia sisoo* is continuing and other new species introduced
4-Late successional stage	*Holoptela sp., Adina cordifolia, Lagerstroemia parviflora, Bombax ceiba, Terminalia belerica* *Trewia nudiflora and Toona ciliate* (these two species can also observe in this stage if the soil condition is moist)	NA	*Acacia catechu* and *Dalbergia sisoo* is disappears and other many species are introducing
5-Pre-climax stage	*Adina cordifolia, Lagerstroemia parviflora, Bombax ceiba, Terminalias, Shorea robusta* *Terminalia alata* (this species is also comes in this stage if soil condition is moist)	NA	*Shorea robusta* can well introduced and some time have dominancy role
6-Climax stage	*Shorea robusta, Lagerstroemia parviflora, Terminalia alata, Adina cordifolia* *Syzygium cumini* (this species also comes in this stage if soil condition is moist)	NA	*Shorea robusta* becomes most dominant species

(Source: Khanna, 1993, p 144)

2.8 Conclusion

The aim of this chapter was to review the contemporary literature concerning with the concept and approach of forest gap model; reparameterization and model testing, and succession process of sal forest in order to identify the gaps towards establishing linkages with the objectives of this study. This chapter initially discussed concept of forest gap model and individual based model in forestry. The Chapter then reviewed the literatures concerning with structure of gap models and it discussed GROW, BIRTH and KILL subroutines. Then it reviewed the relevant gap models for this study. The chapter then reviewed the details of the KIAMBRAM model. Finally, chapter reviewed the sal forest literature relevant for this study.

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CHAPTER 3
METHODOLOGY

The aim of this chapter is to describe the methodology and design of the study procedures that is used to (i) explore the existing floristic structure and composition of mature sal forest (ii) re-parameterize the species specific and site specific parameters that are essential for applying the KIAMBRAM model to simulate the sal forest dynamics, and (iii) test the KIAMBRAM model for mature sal forest dynamics to know the applicability of the model.

3.1 Study area and population

3.1.1 General information of the study area

Chitawan National Park (CNP) and its buffer zone area were selected to assess the different development stages of sal forest. This National Park in the subtropical plane lowlands of southern part of Nepal is the first National Park of the country. The CNP is situated between longitude 83°52' to 84°45'E and latitude 27°20 to 27°40'N. Physical feature of the CNP includes Churia Hills, ox-bow lakes, and the flood plains of three major river systems: Rapti, Reu and Narayani. The park boundaries have been delineated by the Narayani and Rapti Rivers in the north and west, and the Reu River and Someshwor Hills in the south and south-west. It shares its eastern border with the Parsa Wildlife Reserve. Soil of the lower altitude of the CNP specially on flood plains is largely alluvial deposits left by shifting river courses ranging from sandy and coarse loam on new terraces to silty clay loam on older terraces (HMGN, 1968). Map of CNP is presented in Fig 3.1, where green part represents the core area and yellow part represents the buffer area.

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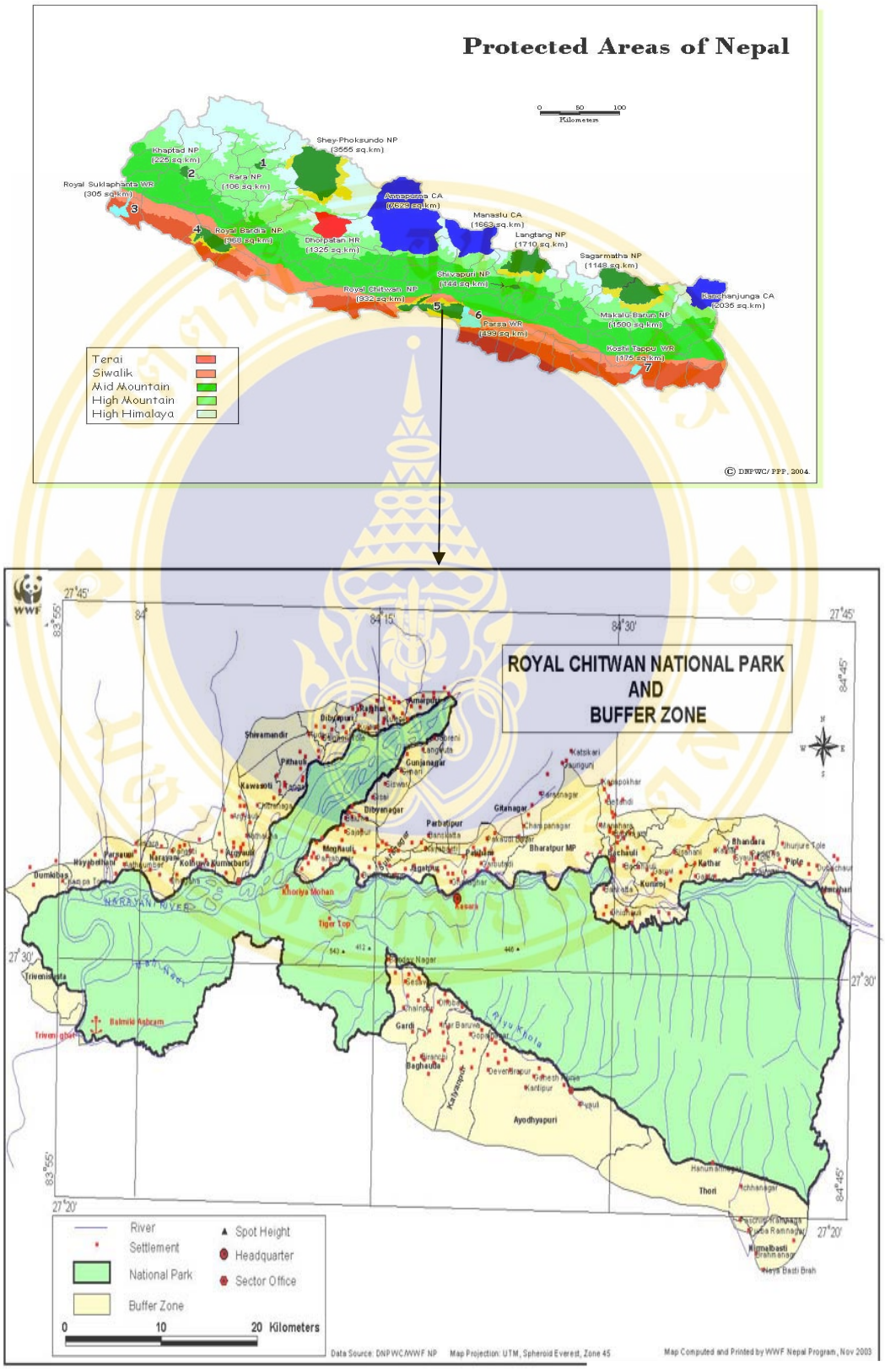

(Source: WWF, Nepal)

Figure 3.1: Map of the study area

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Climate

The climate of CNP is subtropical with high humidity throughout the year. Four distinct seasons (winter, spring, summer, and rainy seasons) occur in the area. The cool winter season occurs from October to February where December and January are the coldest months in the area. Spring begins in March and is soon followed by summer that ends in early June. April, May and June are hot period. Mean annual rainfall is 2000 mm, with 80% as short and heavy rainfall in the summer monsoon from June through September followed by 7 to 8 months of dry season. The minimum day time mean temperature is 16°C in January and 31°C in May to June.

Management history

The population density in Chitwan was very low due to malaria until the 1950s and forest at that time was Rana family's own hunting spot. The Nepal Government in 1962 set aside an area of 54,400 ha south of Rapti River in the Chitwan Valley as a rhino sanctuary when the human population started to increase (Mishra, 1982). In 1964, the Government decided to remove more than 22,000 people from the sanctuary and resettled them outside its boundaries. In 1973, the sanctuary was extended and declared as the first National Park in Nepal. In 1984, it was included in the UNESCO World Heritage list for its internationally important flora and fauna (Straede et al, 2002). The CNP covering a pristine area of 93,200 ha as a core area and additional 75,000 ha buffer zone area.

Biodiversity and major forest types

CNP is renowned for its variety and abundance of rare fauna and flora. There are more than 43 species of mammals, over 450 species of birds, and more than 45 species of amphibians and reptiles in the park. A most dominant forest type of the CNP is terai climax sal forest (Mishra, 1982). About 70% of the park vegetation is predominantly *Shorea robusta* (sal) forest. Purest stands of sal occur on better drained ground. The other vegetation types include riverine forest (7%), hill forest (3%) and grassland (20%) (Sherestha and Dongol, 2006). Riverine forest can further categorized into five different types (UNEP, 1997): (i) *Acacia–Dalbergia* forest dominated by *Acacia catechu* and *Dalbergia sissoo*, (ii) *Bombax–Trewia* forest dominated by

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Bombax ceiba and *Trewia nudiflora*, (iii) Evergreen *Albizia* forest dominated by *Albizia lucida* and *Mangifera indica*, (iv) *Eugenia* woodland dominated by *Syzygium cumini* and *Syzygium operculata*, and (v) *Bombax–Litsea* forest dominated by *Litsea monopetala* and *Bombax ceiba*. Floods, fires and riverine erosion combine to make a continually changing mosaic of grasslands and riverine forests in various stages of succession.

3.1.2 Reasons for selection of CNP and buffer zone for the study

This study requires long run protected forest because of the KIAMBRAM model was originally developed in Australian subtropical protected forest and this study is application of that model. In the context of Nepal, only National Parks and Wildlife Reserves (NPWRs) are the potential available sites for long run protected forest. Though, sal forest is dominated in all the five NPWRs of lowland of Nepal, CNP was selected for this study due to the following reasons: (i) CNP is the oldest protected area in Nepal, therefore it provides a good opportunity to study the long-lived forest, (ii) it lies in central region and it represents the low land sal forest of Nepal, (iii) it has globally significant biological diversity, and (iv) it lies in subtropical region (matching with the KIAMBRAM model), (v) buffer zone of the CNP is older than other and (vi) sal forest in buffer zone tally with the concept of ecosystem approach management (Shepherd, 2004).

Community forest in buffer zone area of CNP provides the opportunity to study the secondary succession stage forest and protected forest after disturbances (Straede et al, 2002; Nagendra et al, 2004), therefore buffer zone community forest was undertaken in this study to incorporate the large number of tree species that exists different development stage of sal forest.

3.1.3 Site selection criteria

Site selection for climax stage sal forest

The vegetation in CNP ranges from early successional floodplain grassland in alluvial floodplains to climax sal forest. The climax sal forest exists in relatively well

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drained flat land and extended in east west direction in CNP. Two different sites were selected around Kasara (head quarter of CNP) to access the dynamics of the climax stage of sal forest. These sites were finalized after the discussion with the National Park officials based on following criteria:

- Climax stage of sal stand should be representative of the lowland sal forest of Nepal.
- Accessibility from the jungle trail.
- Safety during data collection period from wild animals.
- Less disturbances from flood during the field work.
- Comparatively less abundance of tall grasses.

Site selection for successional and disturbed forest

Local communities in the buffer zone area of the CNP are managing their forest during the last 12 years after implementation of buffer zone area management regulation, 1995 for CNP. Two sites were selected from Barandabhar community forest of buffer zone area of CNP. Following criteria were developed for site selection:

- Forest should be formally handed over to the local community.
- Communities should practice protection regimes on their forest.
- Forest should be in similar climatic zone as that of CNP.

3.1.4 Population and sampling

Purpose of defining population here is to link the sampling site and its implication with sal population in context of Nepal. Sal forest covers over 1 million hectare in Nepal (HMGN, 1988) where it covers over 700,000 ha (DoF, 2005) in the lowland (Terai) of Nepal. Total coverage of the sal forest in CNP (total population of this study) is 65,240 ha (70% of CNP covers the sal forest). Purposive sampling method was applied for vegetation measurement. Total 40 ha forest were sampled from the core area of CNP.

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3.2 Structure of the KIAMBRAM model

This study is application of the KIAMBRAM model. Therefore, its structure is important to brief in this methodology section. GROW (growth), BIRTH (recruitment process) and KILL (mortality) subroutines are common components for most of the gap models. The KIAMBRAM model is unique than other stand dynamics gap model because: it consists very large number of trees species (125), inclusion of details of tree establishment process, inclusion of three other subroutine: STRGLE (plantation of the tree), CHABLI (tree fall effect), and LUMBER (harvesting of tree). This model consists of six major components (subroutine), which is simply presented in the Fig 3.2. Two subroutines: LUMBER (logging) and STRGLE (planting) are not undertaken in this study, therefore following sections will only describe the rest four major components of the model and their interrelationship. Model starts from randomly chosen number for the year of CHABLI (tree fall event). Once CHABLI year is read by model, switches of raised soil and mineral soil are activating in the model true or falls. Then, KILL subroutine activate and kills the tree in order to CHABLI (only the event year), then after senescence and through suppression. GROW subroutine calculates the diameter increment of all the trees, including effect of the light and crown competition. BIRTH subroutine adds seedlings in the plot through activating mineral soil and raised soil true or falls. Then it sets all three seed dispersal switches are true. If condition will not match, then the species will be excluded (Roachanakanan, 2002).

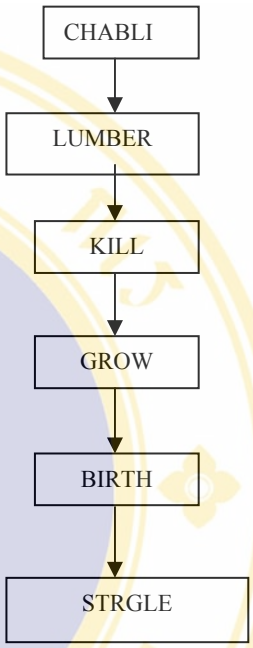

Fig 3.2: A flow diagram of subroutines in the KIAMBRAM model

3.2.1 Growth

Tree growth process in the model is incorporated in GROW subroutine. Growth of the tree is influenced by the factor of light and crowd competition which

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are computed by formula of r(AL) and S(BAR) are mentioned in Chapter-II. Growth is directly proportional to the leaf area and indirectly proportional to tree size.

Light competition in the model is described by calculation of the leaf area index (LAI). In the model, leaf area is assumed as a function of the diameter. However LAI is species specific function but in this model same value of LAI is used for all species. LAI is sum of the leaf area of the tallest tree divided by plot size. The available light is determined by sum of the leaf area of all the taller trees on the plot. The assumption is that all trees have layer of leaf and shorter tree have no effect on taller tree. This is calculated by LAI. Another method for calculating the available light is light extinction coefficient (k). This represents the leaf arrangement and the spectral properties of the leaves in the canopy. In practice, this is derived from previous model whenever applied in similar condition or adjust with diameter frequency. Different light response equations are set in the model for shading effect. In the gap model, growth rate of shade intolerant species is higher than shade tolerant. Crowd competition in the model is expressed for both the soil and nutrient of the plot and it is not different by species and measured by maximum allowable basal area (SOILQ). In this model, value of SOILQ is used 160 m^2 /ha.

3.2.2 Birth

Process of establishment of new seedlings is accounted by BIRTH subroutine. There are many probability factors set for requirements such as: switch of seed dispersal (switch 1 to 3) and soil required (switch 4 to 5), seed longevity and seed phenology. This model incorporates seedling of approximately 1.27 cm DBH size into the simulation plot each year.

3.2.3 Kill

Process of mortality (KILL subroutine) in the model is linkage with overage, suppression and CHABLI event. The CHABLI event for mortality is special in the KIAMBRAM model. Probability of tree mortality in the year of CHABLI is fixed 0.50 to 0.75 and the frequency of CHABLI is set 0.003 in the KIAMBRAM model.

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3.3 Field research process

This study is mostly focused on re-parameterization. Sources for most of the parameters were text book, journal, published or unpublished reports/documents and those were not available in Thailand. Therefore, research work in the field was started from literature review and was ended after consultation with experts (Fig 3.3).

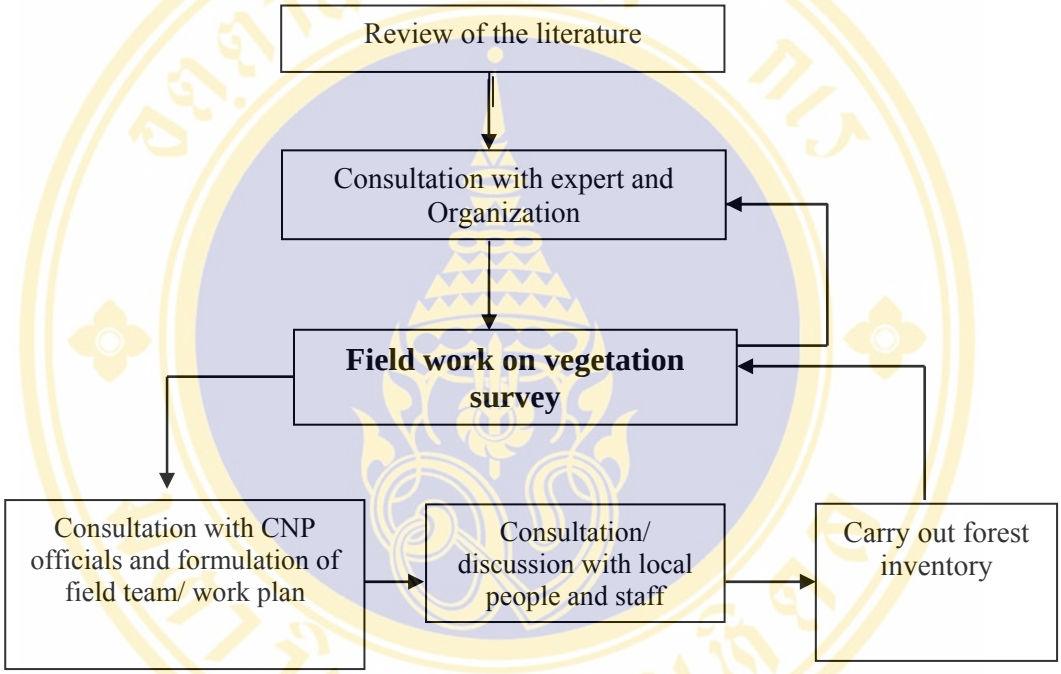

Fig 3.3: Data collection process

3.3.1 Review of the literature

Sal forest related literatures specially species list, SPSP of species, and forest succession information were reviewed and collected. Mainly textbook and journals were reviewed in Forestry Library in Department of Forest Research and Survey, and Central Library of Tribhuwan University, Kathmandu Nepal. It was expected that Department of National Park should have collected documents of past research related to ecology and physiology of sal forest of CNP, but unfortunately not a single report was available there concerning about the ecology and physiology of the sal forest.

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3.3.2 Consultation with experts

Consultation with forestry and plant physiology experts were carried out in Kathmandu (capital of the country) after the completion of literature review but before moving towards the field for data collection. Main purpose of the consultation was to collect the SPSPs and SISPs information which were not available during the reviewing the literatures. Also, consultation was focused for collection of the information regarding the succession stage of the sal forest and gap dynamics of sal forest. Though the researcher had aimed to consult with many professionals, unfortunately most of them were not available and some of them were not agreed to contribute towards the study. According to them, they do not have species specific knowledge and gap model is new knowledge for them. Very few experts contributed in the concerning matter. Especially in case of SPSP, only Dr. Rajendra Gyawali (Appendix-N) made his contribution (Appendix-N). Researcher himself executed expert consultation work. Suggestions and comments made by experts were useful even in the data collection process.

3.3.3 Field work in the study site

Three weeks long field work of this study was carried out on August-September 2007. The survey team was administrated by at least six members: three research assistants including botanist, forester and other three local people (Appendix-M) were involved every day in each plot and team was supervised by the researcher himself. Details of adopted field procedure are as follows.

Instrument and materials used

- Compass
- Global Positioning System device (GPS)
- Measuring tape (linear tape)
- Diameter tape
- Suunto clinometers
- Calibrated bamboo stick
- Nylon rope
- Piece of colored ribbon
- Pegs
- Camera
- Survey forms

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Sample plot layout and establishment

Blocks of the mature sal forest were marked in the map based on above criteria (refer to Section 3.1.3). A 200 m wide and one km long strip (20 ha) from each site were randomly selected in the map for vegetation sampling purpose. Locations of strips were identified with the help of compass and local assistant during measurement. A transect line was placed along the longitudinal direction from the center of the strip. Systematic sampling procedure was applied for established sample plot along the transect line. A 500 m^2 circular shaped sample plot were established at every 100 m interval during the vegetation measurement. Plot center of the first plot was fixed at middle point of the width of strip and wooden peg was punched. Four nylon ropes having each of 12.61 m length (25.22 m diameter of the circle) were laid on the ground from center point of the circle (were tied on the peg) at 90° angular differences. To make the clear boundary of the plot, different piece of colored ribbon were fixed at the end point of the four nylon rope and additional four at the middle point of the arc of the two consecutive ropes. In such a way total eight ribbon points were fixed at the circumference of the plot to fix the boundary of the plot. Beside this, every nylon rope was movable and they were easily used when any tree in the boarder is confused during the measurement. Sample pots were established at the regular interval of 100 m apart along with transect line.

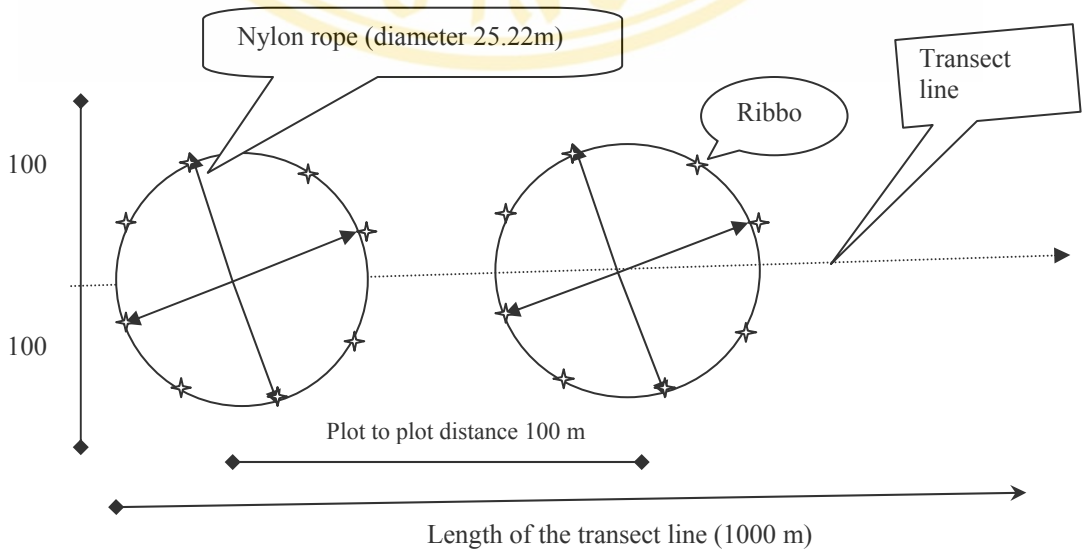

Fig: 3.4 Layout of the sample plot and transect line

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Transect line layout and establishment

Transects were meant to be straight lines with a sampling plot at every 100 m distance (Fig.3.4). Compass and GPS were used to layout and move along the transect axis (DoF, 2004). The distance between two consecutive plot center (length of transect) was measured with the help of measuring tape (linear tape).

Measurement on sample plot and discussion in the team

DBH and height of all individual trees having DBH above 1.27[1] cm were observed and recorded in each sample plot on the data collection form (Appendix-A). Diameter tape was employed to measure the DBH of tree. Similarly, Suunto clinometer was used to measure the height of the larger sized trees. In addition, calibrated (scaled) bamboo stick was also used to measure the height of the smaller tree. Small regeneration, herbs and shrubs were not measured in the study. Moreover, in each plot, discussion were held with local people for knowing the changes of ecological and physiological parameter of sal forest based on issues mentioned in Appendix-B. Most of the trees were identified by field team. Leafs were collected and photo were taken in case of unidentified tree species and latter consulted with local people and experts but only nominal species were not identified in the field. Total of 20 ha sal forest strip (200 m * 1000 m) were measured through 10 sample plots in each site. In this way, total 40 plots and 80 ha forest were sampled from the study area in this study.

3.4 Data analysis

3.4.1 Applicable software

Microsoft Excel software package was used for calculation of sample plot data and computation of species specific individual tree growth table**.** This study is application of the KIAMBRAM model therefore KIAMBRAM model programming

[1] Selecting initial DBH 1.27 cm is because of the KIAMBRAM model has considered this as the initial diameter of recruitment.

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was used for forest simulation. Before using the KIAMBRAM model programming, researcher asked for permission with the model developer 'Professor Ian R. Noble'.

3.4.2 Process of analysis and interpretation

3.4.2.1 Existing mature forest condition

Basal area, stem density, diameter distribution, canopy height, and species distribution pattern in the stand were computed from sample plot data by using following formulae and methods to calculate and interpret the condition of observed mature sal forest (DoF, 2004).

Basal area

- Basal area (BA) of the individual tree $BAi = \frac{\pi * DBH^2)}{4}$ (cm^2)
- Basal area of the plot = sum of BA of all the trees in the plots = $\sum BAi$
- Basal area of the stand[2] $(m^2/ha) = \sum BAi * \frac{20}{(100 * 100)}$
- Basal area of the individual species $(m^2/ha) = \sum BAspi * \frac{20}{(100 * 100)}$

Stem density

- Stem density of the plot = sum of al the individual in the plot = $\sum Stem\ i$
- Stem density of the stand (no/ha) = $\sum Stemi * 20$
- Stem density of the individual species (no/ha) = $\sum Stem\ spi * 20$

Diameter distribution pattern

DBH of all the individual trees were grouped into different diameter classes and diameter frequency tables were prepared for stand level and species level.

[2] Plot is converted into ha by multiplying 20 (because plot size is only 500 m^2 and 1 ha is 10,000 m^2) where cm^2 is converted into m^2 by dividing 100*100.

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Diameter frequency table were converted in terms of per ha. Graphs and tables were used for interpretation of the diameter distribution information.

Canopy height

Though the height of all the individual trees were available in the sample plot data, only three tallest trees from each sampling plots were chosen for canopy height computation (followed by Timilsina, 2005). In this way height of the tallest 60 trees were employed in canopy computation. Stand level and species level tallest height were computed. Descriptive statistics: mean and SD were used for computation and interpretation.

Species distribution pattern

Species distribution pattern was computed through species abundant in number of sample plot.

3.4.2.2 Re-parameterization of model

Species associated in the sal forest (species list) were prepared first through literature and finalized in the field inventory process.

Maximum diameter (D_{max}) and maximum height (H_{max}) of the tree were mostly recorded from the text book "Manual of afforestation in Nepal, volume 2, Jackson (1994)". D_{max} and H_{max} of the remaining species were looked in "The silviculture of Indian trees, volumes I, II and III, Troup (1921)". Individual tree growth table were prepared for all the species by using periodic or any single year's growth data. δD_{max} and Age_{max} of all the species were computed through respective growth table. Adopted computation process for δD_{max} and Age_{max} and G are described in Appendix-I and Appendix-J. Shade tolerant, seed phenology, seed longevity, seed dispersal and types of soil required for all the species were collected from text books "Principle and practice of silviculture, Khanna (1993)" and above mentioned two books. Three alter methods were applied to determine the above parameters which were not found in the above references. They were: (i) Expert's opinion (opinion) was used through consulting expert of forestry and plant physiology, (ii) Researcher's personal experience also was used to fix some of the parameters of his experiences species

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(researcher is a forester, see biography). (iii) Field level consultation (name list of involved people is mentioned in Appendix-N) was also used to determine the parameters for those not found from the above methods and sources. Method of filed level consultation was adopted through asking the parameter one by one in the group in the sample plot and concrete decision was made after interaction in the group. The field level consultation method found more effective because different experiences people were involved in the discussion and vegetation measurement process. Re-parameterization is the main focus of this study, therefore its details is described in Chapter 4.

3.4.2.3 Model testing

After finalizing the SPSPs for all the species, excel sheet (given in the KIAMBRAM programming for input file) were prepared. After setting all SPSPs and SISPs in the model, model was run. Output files were recorded and compared with recent inventory data and available literatures. Model was run several times by changing the parameter until the result does not match satisfactory. Parameters that show the satisfactory result were recorded. Model simulated results at the mature stage were compared with existing mature forest condition of empirical data. Model simulated species composition at different stages was compared with literature.

3.5 Anticipated result

This study was an attempt to document and provide application of computer model in lowland sal forest. It was expected that re-parameterization and testing of the forest gap model (the KIAMBRAM model) will aid framework for synthesizing information about the attributes of sal forest in Nepal. The output of this study i.e. tested model program somehow will provide a vehicle for projecting the possible ecosystem consequences of lowland sal forests dynamics. Moreover, following results were expected from this study.

a. Existing condition of the mature sal forest: stem density (each pecies, and total), basal area (each species and total) and diameter distribution (each species and total).

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b. Species specific parameters (D_{max}, H_{max}, Age_{max}, diameter growth, height growth, mean annual increment, shade tolerance level, seed phenology, seed longevity, seed dispersal agent, soil required) of all the tree species associated in sal forest in collective form.
c. Site specific parameters for sal stand dynamics.

All of the above findings are feasible to provide tangible feedback to the policy and planning decision makers and explore through appropriate means.

2.6 Conclusion

This chapter reviewed the overall methodology applied for this study. Chapter initiated with study area and population, at the middle part it discussed about structure of the KIAMBRAM model. Chapter also provided an overview of method of data collection. Then chapter described the applicable software for data analysis and method of data analysis. The chapter concluded with the anticipated result.

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CHAPTER 4
RESULTS AND DISCUSSION

Theoretical background and methodological framework for exploring the existing floristic structure and composition of the mature sal forest, reparameterize the KIAMBRAM model to simulate the sal forest dynamics, and test of the KIAMBRAM model to the sal forest are discussed in the previous chapters. Forest inventory sampling frame is also elaborated in Chapter III. Aim of this chapter is to present the results of the analyzed data and to make discussion on the obtained results.

This chapter is divided into three specific sections concerning with a) existing floristic structure and composition of climax sal forest, b) re-parameterization of model parameters, and c) test of the model.

4.1 Existing floristic structure and composition of climax sal forest

An area of 40 ha was sampled from intact lowland matured sal forests of Chitawan National Park (CNP) of Nepal through establishing 20 sample plots. Due to the presence of over aged and large sized trees, fewer number of middle sized trees, poor tree vegetation at the ground cover level and mature soil phenomenon, the forest was considered as the climax stage sal forest. Altogether 42 tree species (with DBH>1.27 cm) were recorded in the study site. *Shorea robusta* was the most dominant species. Five major parameters: basal area, stem density, diameter distribution, canopy layer and species distribution pattern were analyzed to explain the existing floristic structure and composition of the sal forest as follows.

4.1.1 Basal area

Average basal area across the 20 plots was 26.98 m^2/ha (Table 4.1), the minimum was 10.36 m^2 /ha and the maximum was 49.56 m^2/ha. Basal area of all the

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sample plots is presented separately in Appendices C (II) and D (II). Average basal area of the stand is low in comparision with the Terai *S. robusta* forest (36 m^2/ha) of Bardiya National Park of western Nepal (Shrestha and Jha, 1997) but it is within the range of 16.0-61.1 m^2/ha as reported by Singh et al. (1995) in Corbett National Park, India. Presence of low basal area in this study is due to less abundant of bigger sized tree (over 80 cm DBH) and presence of very less number of middle sized trees. Reasons of not finding the bigger sized tree may be due to selective illegal cutting of the tree at the time before protection program was started especially during 1950s. Another reason may be due to the use of forest as open grazing space and may be due to the collection of the forest product before the declaration of the protection area. Other reasons for having few number of middle sized tree may be due to competition of light (suppression), because most of the trees in the forest were shade intolerant and they need sufficient light for their growth and development.

At the species level, *S. robusta* showed the average basal area of 21.01 m^2/ha (minimum 0.12 m^2/ha [1] and maximum 44.00 m^2/ha). Only *S. robusta* had occupied 77.85% of basal area of the stand. This value is close to the basal area value of the *S. robusta* coverage of 68.20% found in the western lowland sal forest (Timilsina et al, 2007). Average basal area of the few dominant species is presented in Table 4.1 and details are presented in Appendix-E. Second highest basal area was *Cleistocalyx operculatus* (1.97 m^2/ha) which covered only 7.30% of basal area at the stand. Study of Timilsina et al (2007) in western Nepal has also found that this species has second highest basal area of 7.90% in *S. robusta-Buchanania latifolia* forest. Similarly, another 4 species having basal area more than 1% are: *Holarrhena pubescens* (0.85 m^2/ha, 3.20%),

Table 4.1: Basal area of mature sal forest (m^2/ha)

Species	Average BA	%	SD
Shorea robusta	21.006	77.85	7.548
Cleistocalyx operculatus	1.967	7.30	1.983
Holarrhena pubescens	0.854	3.17	1.314
Largerstroemia parviflora	0.746	2.76	1.004
Dillenia pentagyna	0.736	2.73	0.602
Terminalia bellirica	0.348	1.29	0.586
Litsea monopetala	0.160	0.60	0.152
Bombax ceiba	0.130	0.50	0.247
Desmodium oojeinense	0.122	0.45	0.232
Adina cordifolia	0.114	0.42	0.217
Others	0.798	2.96	1.159
Total	**26.981**		

[1] This information is collected from plot-3. Sample plot was established randomly in grass dominant site. Only 3 plants of *S. robusta* species were recorded from this plot and all of them were less than 6.0 cm DBH. Therefore, basal area of *S. robusta* was little in this plot.

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Largerstroemia parviflora (0.75 m^2/ha, 2.76%), *Dillenia pentagyna* (0.74 m^2/ha, 2.73%), and *Terminalia bellirica* (0.35 m^2/ha, 1.30%). In the present study, only the aboved mentioned six species have covered more than 95% basal area of the stand. Other remaining 36 species have covered very lower amount of basal area. Basal area of the dominant species will be compared with model simulated data in Section 4.3.

4.1.2 Stem density

The average stem density across the 20 plots in the study area was 874 stem/ha, the maximum was 2200 stem/ha and minimum was 320 stem/ha. Stem density of all the sample plots are presented separately in Appendices C (I) and D (I) and summary of the both of the site is presented in Appendix-E. This observed stem density is lower than 2371 stem/ha (608 trees and 1723 saplings) of the central low land sal forest of Nepal reported by Webb and Sah (2003). Poor density at the sapling level may be due to insufficient light at the lower canopy level and most of the species are either light demander or intermediate light demander. Therefore they can not grow in minimum or no light condition, which is known as suppression effect (Timilsina et al, 2007). At the species level, *S. robusta* was found with highest stem density among the other species. Average stem density of *S. robusta* was 223 stem/ha (minimum 40 stem/ha and maximum 520 stem/ha), it reflects to 25.51% of stem covered by this species. Similarly, the study carried out by Timilsina et al (2007) also reported that the averages of 29.00% of stems were covered by *S. robusta* alone in western Nepal. Webb and Sah (2003) found that 36.30% stem belong to *S. robusta* in natural sal forest of central Nepal. However, total observed stem density was found comparatively low in this study but the ratio of the *S. robusta* stems to the total stand stem is found similar

Table 4.2: Stem density (stem/ha) of mature sal forest

Species	Mean	%	SD
Shorea robusta	223	25.51	135.30
Litsea monopetala	135	15.45	136.00
Dillenia pentagyna	120	13.73	86.00
Cleistocalyx operculatus	113	12.93	79.70
Holarrhena pubescens	50	5.72	54.00
Largerstroemia parviflora	46	5.26	39.80
Mallotus philippensis	37	4.23	53.20
Aporusa octandra	30	3.43	50.00
Others	120	13.74	80.00
Total	**874**		

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with the other studies and it ranges 25-40%. Observed stem density of the dominant species is presented in Table 4.2. *Litsea monopetala* was found with the second largest stem density (135 stem/ha, 15.45%) but size of the stems were very small. This species was not recorded as a most abundant species neither by Timilsina et al (2007) in Western Nepal nor by Webb and Sah (2003) in Central Nepal. Other higher abundant species in this study were: *Dillenia pentagyna* (120 stem/ha, 13.73%), *Cleistocalyx operculatus* (113 stem/ha, 12.93%), *Holarrhena pubescens* (50 stem/ha, 5.72%), *Largerstroemi parviflora* (46 stem/ha, 5.26%), *Mallotus philippensis* (37 stem/ha, 4.23%) and *Aporusa octandra* (30 stem/ha, 3.43%). The rest of the other species (34 species) were found with smaller stem density.

4.1.3 Diameter distribution

Diameter distribution at the stand level and species level were analyzed. Diameter class vs numbers of stems at the stand level are presented in Figure 4.1.

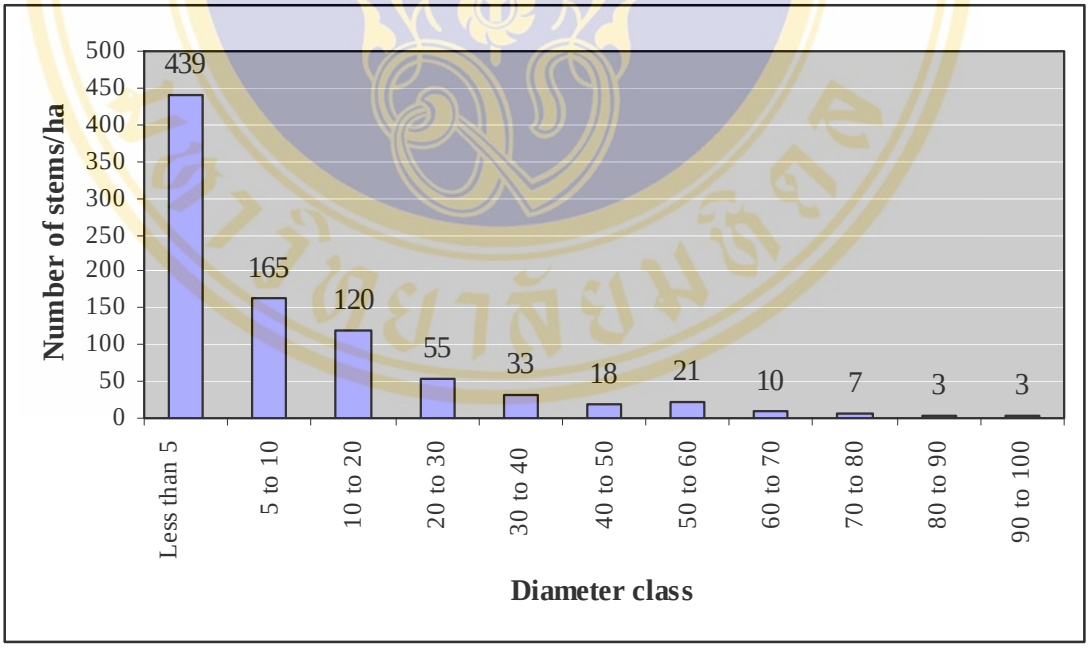

Figure 4.1: Diameter distribution at the stand level

Figure 4.1 shows that more than 50% trees lies in lowest diameter class (DBH 1.27-5.00 cm). Trees having DBH 5-10 cm were 165 stem/ha (18.88%). It comprises of trees having less than 10 cm DBH were coverd 69.11% stems of the stand. Trees >30cm DBH found 94 trees/ha and tress>80 cm DBH were only 6 stem/ha. Diameter distributions for all the species were analyzed and presented in Table 4.3.

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Table 4.3: Species diameter distribution

		Less than 5 cm	5- 10	10-15	15-20	20-25	25- 30	30- 35	35- 40	40- 45	45- 50	50- 55	55- 60	60- 65	65- 70	70- 75	75- 80	80- 85	85- 90	90- 95	95- 100	**Total**
1	*Shorea robusta*	70	16	19	13	12	12	10	13	11	6	9	10	5	5	4	3	1	1	2	1	223
2	*Litsea monopetala*	118	17																			135
3	*Dillenia pentagyna*	54	48	9	5	1	2		1													120
4	*Cleistocalyx operculatus*	28	29	21	17	8	5	2	2			1										113
5	*Holarrhena pubescens*	26	13	6	3	1													1			50
6	*Largerstroemia parviflora*	22	3	3	9	5	3	1														46
7	*Mallotus philippensis*	32	4		1																	37
8	*Aporusa octandra*	25	4	1																		30
9	*Bauhinia purpurea*	6	3	1																		10
10	*Actinodaphne angusifolia*	6	2	1																		9
11	*Trewia nudiflora*	7	1	1																		9
12	*Terminalia bellirica*	2	3			1		1				1										8
13	*Phyllanthus emblica*	3	4																			7
14	*Ehretia wallichiana*	4	3																			7
15	*Casearia graveoles*	3	1			2																6
16	*Semecarpus anacardium*	4	1																			5
17	*Diospyros malabarica*	2	1		2																	5
18	*Anthocephalus chinensis*	5																				5
19	*Syzygium cumini*	3	1																			4
20	*Myrsine semiserrata*	3	1																			4
21	*Lannea coromandelica*	4																				4
22	*Xeromphis utiginosa*		1	3																		4
23	*Garuga pinnata*		1		1			1														3
24	*Bridelia retusa*	1		2																		3
25	*Adina cordifolia*		1			1	1															3
26	*Careya arborea*		3																			3
27	*Albizia lebbeck*	2		1																		3
28	*Glochidion velutinum*	2																				2
29	*Butea monosperma*	2																				2
30	*Cassia fistula*	2																				2
31	*Grewia optiva*					1																1
32	*Terminalia chebula*		1																			1
33	*Bischofia javanica*								1													1
34	*Duabanga grandiflora*				1																	1
35	*Cornus oblonga*	1																				1
36	*Randia dumetorum*		1																			1
37	*Carpesium nepalense*	1																				1
38	*Buchanania latifolia*		1																			1
39	*Cassine glauca*	1																				1
40	*Desmodium oojeinense*								1													1
41	*Dalbergia latifolia*		1																			1
42	*Bombax ceiba*									1												1
		439	**165**	**68**	**52**	**32**	**23**	**15**	**18**	**12**	**6**	**11**	**10**	**5**	**5**	**4**	**3**	**1**	**2**	**2**	**1**	874

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Data of Table 4.3 shows that *S. robusta* was present in all the diameter classes. The highest density of *S. robusta* was in 1.27-5.00 cm DBH class 68 stem/ha. *S. robusta* was higher abundant below 10 cm DBH class (86 stem/ha, 38.50%) and above 30 cm DBH class (82 stem/ha, 36.80%). Above 90 cm DBH only *S. robusta* was presences. However, *Litsea monopetala* was the second largest stem density but it was completely absent in above 10 cm DBH class. This species was most abundant in 1.27-5.00 cm DBH class (119 stem/ha, 26.80%). *Dillenia pentagyna* was the third highest stem density, but it was completely absent above 40.00 cm DBH class, which was most abundant in 5.00-10.00 cm DBH class (29%). Other dominant species in 5.00-10.00 cm DBH class were *Cleistocalyx operculatus*, *L. monopetala* and *S. robusta*. At the tree level (>30cm DBH class) forest was dominated by *S. robusta* (85%) followed by *C. operculatus* (5%), *Terminalia bellirica* (2%) and very rarely (1%) by other species such as *L. parviflora*, *D. pentagyna*, *Holarrhena pubescens*, *Desmodium oojeinense*, *Bombax ceiba* and *Garuga pinnata*. Four species were present in higher DBH classes >50.00 cm and density of species was *S. robusta* 41 stem/ha, *C. operculatus* 1 stem/ha, *T. bellirica* 1 stem/ha and *H. pubescens* 1 stem/ha. *Shorea robusta* was found density over 90.00 cm DBH class was 3 stem/ha and no any trees found over 100 cm DBH.

Different size classes; sapling (less than 10 cm DBH), pole size tree (DBH 10-30 cm), middle sized trees (30-50 cm DBH) and large sized trees (>50 cm DBH) were also analyzed to summarized the stand size at the broader level. Result of the analysis is presented in Figure 4.2. Figure shows that saplings covers 69.11% (604 stem/ha) stem density, small sized trees (pole) cover 20.02% (175 stem/ha), middle sized trees cover 5.83% (51stem/ha) and larger sized trees only cover 5.03% stem (44 stem/ha).

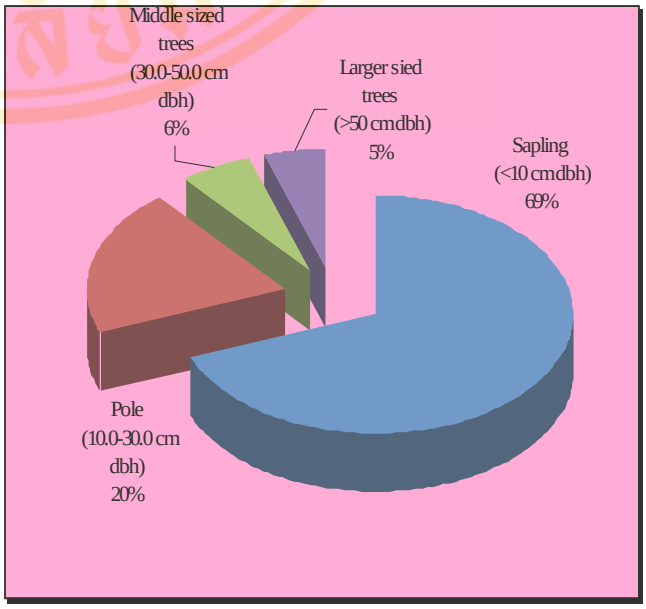

Figure 4.2: Sapling, pole and tree density

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4.1.4 Canopy height

Three tallest trees from each sampling plots were chosen to know the average top canopy height of the sample plot (detais of tree is in Appendix-F). The average top canopy height of the stand found 31.24 m (SD 2.56 m). Top canopy heights of the sampled plots are presented in Figure 4.3. Tallest top canopy was 35.5 m in plot-10 and lowest top canopy was 25.2 m in plot-1.

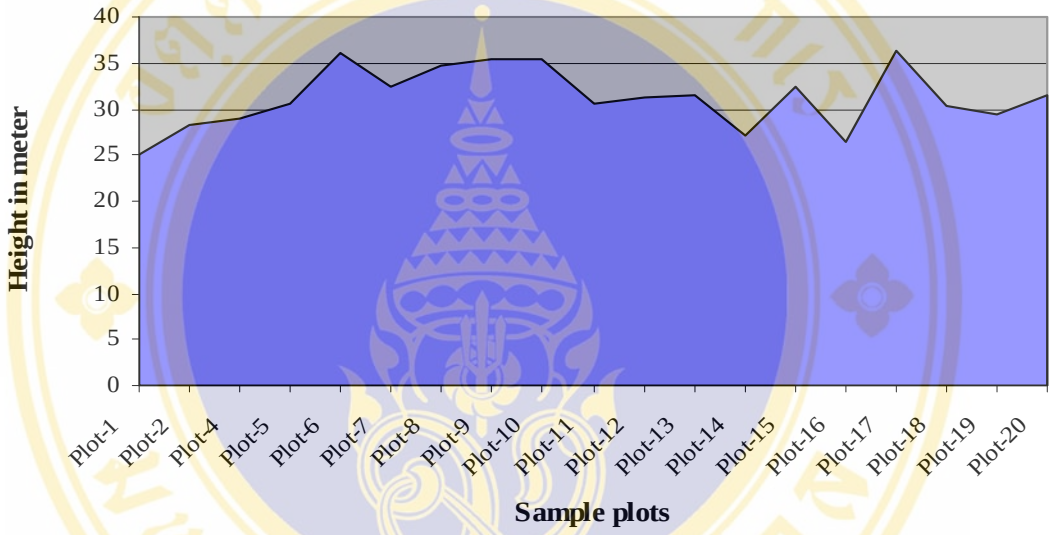

Figure 4.3: Height of the top canopy tree

Tree heights were classified into five different height groups; less than 5 m, 5-10 m, 10-20 m, 20-30 m and more than 30 m. Trees more than 30 m height were 36/ha (7^{th} column of Table 4.4) and all belongs to *S. robusta.* It implies that dominant tree species of the climax sal forest was *S. robusta.*

Table 4.4: Species-height distribution

	Species	Height in meter					Total
		Less than 5	5 to 10	10 to 20	20 to 30	Over 30	
1	*Actinodaphne angusifolia*	8	1	2			11
2	*Adina cordifolia*		1				1
3	*Albizia lebbeck*	3					3
4	*Anthocephalus chinensis*	5		1			6
5	*Aporusa octandra*	26	3				29
6	*Bauhinia purpurea*	9	1	1			11
7	*Bischofia javanica*						0

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Table 4.4: Species-height distribution (cont.)

	Species	Height in meter					Total
		Less than 5	5 to 10	10 to 20	20 to 30	Over 30	
8	*Bombax ceiba*				1		1
9	*Bridelia retusa*	1	2				3
10	*Buchanania latifolia*		1				1
11	*Butea monosperma*	2					2
12	*Careya arborea*		3				3
13	*Carpesium nepalense*	1		2			3
14	*Casearia graveoles*	3	1				4
15	*Cassia fistula*	2					2
16	*Cassine glauca*	1		23			24
17	*Cleistocalyx operculatus*	53	35		2		90
18	*Cornus oblonga*	1					1
19	*Dalbergia latifolia*	1		1			2
20	*Desmodium oojeinense*			8			8
21	*Dillenia pentagyna*	84	27	2	1		114
22	*Diospyros malabarica*	2	1				3
23	*Duabanga grandiflora*	1					1
24	*Ehretia wallichiana*	7		1			8
25	*Garuga pinnata*	1	1				2
26	*Glochidion velutinum*	2		1			3
27	*Grewia optiva*			1			1
28	*Holarrhena pubescens*	35	13		1		49
29	*Lannea coromandelica*	4		18			22
30	*Largerstroemia parviflora*	24	2	1	2		29
31	*Litsea monopetala*	118	16				134
32	*Mallotus philippensis*	33	4				37
33	*Myrsine semiserrata*	4					4
34	*Phyllanthus emblica*	5	2				7
35	*Randia dumetorum*	1					1
36	*Semecarpus anacardium*	4	1	51			56
37	*Shorea robusta*	77	21		38	*36*	172
38	*Syzygium cumini*	4		1			5
39	*Terminalia bellirica*	4			3		7
40	*Terminalia chebula*		1				1
41	*Trewia nudiflora*	7	2				9
42	*Xeromphis utiginosa*	1	3				4
		534	142	114	48	36	874

At the sub-canopy level (20m to 30 m height), *S. robusta* was dominated. Average height of the species at this stage and their abundant is presented in Table 4.5. Occasionally, *Cleistocalyx operculatus*, *Terminalia bellirica* and *Largerstroemia parviflora* also were presented in the sub canopy layer but due to fewer occurrances of these species at this level, their influence at the sub canopy layer was minimal.

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Table 4.5: Species at sub-canopy level

Species	Ht (m)	Abundant (%)
Shorea robusta	25.75	79.17
Cleistocalyx operculatus	25.00	4.17
Terminalia bellirica	24.50	6.25
Largerstroemia parviflora	20.25	4.17
Others		6.25

Similarly, lower canopy (less than 5 m height) was dominated by *Litsea monopetala* and *Dillenia pentagyna* (Table 4.6). At this level, *Cleistocalyx operculatus, Shorea robusta, Mallotus philippensis* and *Holarrhena pubescens* also were occassionally present in the canopy. Average height of the lower canopy was 2.98 m computed from 534 individuals of this category.

Table 4.6: Species at lower-canopy level

Species	Ht (m)	Abundant (%)
Litsea monopetala	3.10	22.10
Dillenia pentagyna	2.95	15.73
Shorea robusta	2.90	14.42
Cleistocalyx operculatus	3.16	9.93
Holarrhena pubescens	2.70	6.55
Mallotus philippensis	3.00	6.18
Aporusa octandra	3.00	4.87
Largerstroemia parviflora	2.75	4.49
Others		15.73

The understory was poorly stocked and dominated by different species of shrubs and grasses but they were not accounted in the sampling process. Figure 4.4 showed the dominancy of grasses in the lower canopy level. Abundant of the grass at the lower canopy level was higher in relatively low altitude sites and fire disturbed site.

Figure 4.4: Grass dominated in lower canopy

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4.1.5 Species distribution pattern

To know the uniformly distributed species across the entire sampled plot, species distribution analysis was carried. Species that were found in more than 10 sample plots are present in Table 4.7.

Table 4.7: Frequency of the species distribution

Species	Represented plots	%
Shorea robusta	20	100
Dillenia pentagyna	17	85
Cleistocalyx operculatus	16	80
Largerstroemia parviflora	14	70
Litsea monopetala	14	70
Holarrhena pubescens	12	60
Mallotus philippensis	7	35
Phyllanthus emblica	5	25
Actinodaphne angusifolia	5	25
Bauhinia purpurea	5	25

Species distribution analysis showed that only *S. robusta* was eventually distributed across 20 sampled plots. *Dillenia pentagyna* was found into 17 sample plots and other four species: *Cleistocalyx operculatus, Largerstroemia parviflora, Litsea monopetala* and *Holarrhena pubescens* were found in more than 10 sample plots. Therefore, it can be mentioned that they are eventually and well distributed species in the sampled forest. Four species; *Mallotus philippensis, Phyllanthus emblica, Actinodaphne angusifolia* and *Bauhinia purpurea* were presences more than 5 sample plots but less than 10 sample plots. Another 13 species; *Terminalia bellirica, Bridelia retusa, Careya arborea, Ehretia wallichiana, Albizia lucidior, Garuga pinnata, Diospyros malabarica, Aporusa octandra, Syzygium cumini, Myrsine semiserrata, Lannea coromandelica, Cassia fistula* and *Casearia graveolens* were present more than 2 sample plots. But remaining 19 species only represented in the single sample plot. They found poor distribution and they may not be common abundant species in sal forest. One of the major reasons of poor replication of these species across the sample plots may be due to that number of sample plots was minimal in this study. Increasing the sample plots with covering wider cluster may help to answer the issues raised.

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4.2 Re-parameterization of model

Second objective of this study was to re-parameterize the KIAMBRAM model in the context of the sal forest. Following three tasks: (a) preparing the list of the sal forest tree species, (b) valuing the species specific parameters (SPSPs) for all the listed species, and (c) valuing all the site specific parameters (SISPs) were assigned for model re-parameterization process which is mentioned in the following sections. Re-parameterization procedure applied in this study could be important therefore they are also briefly described in the sections below.

4.2.1 The species list and sources

Preparation of lists of the maximum number of tree species that occurs in different development stages in the sal forest succession was the major goal for this stage. Other previous studies related to composition of sal forest in the lowland of Nepal were reviewed. Recent two studies in mature lowland sal forest of Nepal showed that at least 28 tree species were found in western Nepal (Timilsina et al, 2007) and 37 trees species were found in Central Nepal (Webb and Sah, 2003). This study site (CNP) lies in the middle part of above two sites. It was assumed that common species of both sites are also presented in the current study site. List of species was prepared through considering above assumption and some other basic ecological aspects of the sal forest such as: *S. robusta* species can grow wider variety of soil condition and geography (Troup, 1921), and it is an extremely gregarious species (Champion and Seth, 1968). In this way, total of 35 species (probable species composition of sal forest) were prepared before moving to the field (Appendix-G).

During the field inventory of the present study, total of 42 tree species were recorded from the core area of CNP. This list was not sufficient to predict species composition of other different successonal stages of the sal forest because these species were only related to mature sal forest. To address the above issues, field inventory was carried out in two other different sites of community managed forest from the buffer zone area of CNP. Data of the community forest were categorized into

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two parts: secondary successional forest[2] and protected disturbed forest[3]. Total of 12 new species were recorded from successional forest than mature sal forest. One new species were recorded from the disturbed forest site than successional forest. After comprising these lists, total 13 new species were found outside the protected area (Appendix-H). In this way, altogether 55 tree species list were prepared. All the sources are summarized in Table 4.8. All the 35 species of original list[4] are common in the new list of 55 species. However, the list of 55 tree species prepared in the study site is large enough but it may be still lack of many other important sal associative species and this list may not be sufficient to predict the sal forest for wider coverage area. Due to many limitations, sample collection from the wider geographic ranges and different successional stages was beyond the capacity of this research. Therefore, prepared list of species is not the final list and further improvement is necessary.

Table 4.8: Number of species collected from different sites

Types of forest	Sites	# of species recorded	Types of species	Added new species list
Protected forest	Sites-1 and -2 (combined)	42	-	42
Successional forest	Site-3	35	12 new species were found.	12
Disturbed forest	Site-4	33	25 species were common within protected area and 32 were common within Site-3	1

[2] In past site was covered by sal forest and it was completely destroyed. Most part of the forest was fragmented and converted into small barren patches. Local community has been protecting the remain since last 10 years, therefore forest is naturally regenerating so called successional forest. Sample plot was designed in such area and vegetation was measured. Stand age of this forest is 10 years.

[3] Forest was partly disturbed but not completely converted into barren area. Partly forest area was started to protect since last 10 years, so named protected disturbed forest. Stand age of upper canopy is the same as stand of CNP but newly stands are about 10 years.

[4] Tentatively prepared species list before field measurement.

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However, the sal forest is not in species rich but prepared tree species list in this study shows longer list as compare to species list of other gap models (Table 4.9). According to Table 4.9, (a) 40 species were listed in the first JABOWA model to simulate the northern hardwood of Hubbard Brook Forest in New England USA, (b) 33 species were listed in the JABOWA-FORET model for simulation of Appalachaian Deciduous Forest in Tennessee, USA, (c) 36 species were listed in the FORICO model for simulation of lower montane rain forest in Puerto Rico and (d) 28 species were listed for the QUTENIQUA model simulation for mixed tropical evergreen forest in the south cape, South Africa. The 55 species list is much lower than 125 species listed in the KIAMBRAM model for simulation of sub-tropical rain forest in Australia. Though the prepared species list is long, only about 10 tree species were most common across the sample plots and rest of the species were found either rare or short lived pioneer species. The sal forest existed in the cluster and species composition is sensitive to locality factor (Troup, 1921; Khanna, 1993; Jackson, 1994), where small variation in the sites found significantly differences of species composition. Similarly, Timilsina et al (2007) also found variation of the species composition within the same cluster and they grouped three types of sal communities in their study area. Therefore, single set of species list may not be appropriate to predict the sal forest dynamics, for the particular site specific simulation. All the 55 tree species are present in Appendix-H with their local name and family name.This 55 species list is set for CNP and its periphery.

Table 4.9: List of species in different gap model

Models	Number of Species
First JABOWA model	40 species
JABOWA-FORET model	33 species
FORICO model	36 species
QUTENIQUA model	28 species
KIAMBRAM model for for subtropical rain forest in Australia	125 species
Application of KIAMBRAM in subtropical sal forest in Nepal	55 species

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4.2.2 Determination of SPSP

In the parameter determination process, species specific parameters for each of the species were broadly classified into two categories: (1) growth related parameters and (2) birth related parameters. It was critical task to collect/determine the specific parameters for each of species seperately because no any previous studies were found related to these types of parameterization for sal forest species. Mostly, secondary sources (literature, published and unpublished materials/ reports, web based information), mathematical manipulation with the help of known values, and other different primary sources such as: consultation with experts, participatory method with local people, and personal experience of researcher were used to accomplish the parameter determination of all species. Following sections will describe details of parameter determination process.

4.2.2.1 Growth related parameters

(a) Maximum diameter (D_{max}) and maximum height (H_{max})

Maximum diameter **(**D_{max}) and maximum height (H_{max}) of the trees were recorded mostly from the text book “Manual of afforestation in Nepal, volume 2, JK Jackson, 1994”. D_{max} and H_{max} of the remaining species were looked in “The silviculture of Indian trees, volumes I, II and III, Troup (1921 and revised version)”. Some of web based sources were also used for information collection but they were less emphasized. Expert’s options were also used to determine D_{max} and H_{max} of those which were not found by the above methods. D_{max} and H_{max} values for few species were finalized during the field work after consultation with local people if any species were found lack of D_{max} or H_{max} value or in the case of confusion in the collected data. Maximum magnitudes were used when many values were available for single parameter. The values of D_{max} and H_{max} for all 55 species and their respective sources are presented in Tables 4.10 and 4.11, respectively.

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Table 4.10: Maximum diameter (D_{max}) of sal forest species

	Species	D_{max} (cm)	Sources		Species	D_{max} (cm)	Sources
1	*Acacia catechu*	50	NA	29	*Duabanga grandiflora*	80	NA
2	*Actinodaphne angusifolia*	45	NA	30	*Ehretia wallichiana*	25	NA
3	*Adina cordifolia*	220	Troup, 192, p 616 and Jackson, 1994 p 363	31	*Ficus beghalensis*	100	NA
4	*Aegle marmelos*	40	NA	32	*Ficus benjamina*	60	NA
5	*Albizia lebbeck*	50	http://en.wikipedia.org/wiki/Albizia_lebbeck	33	*Garuga pinnata*	55	NA
6	*Anogeissus latifolius*	90	Troup, 1921, p543	34	*Glochidion velutinum*	45	NA
7	*Anthocephalus chinensis*	50	NA	35	*Grewia optiva*	50	NA
8	*Aporusa octandra*	40	NA	36	*Gmelina arborea*	70	NA
9	*Bauhinia purpurea*	30	Jackson, 1994, p 431	37	*Holarrhena pubescens*	30	NA
10	*Bauhinia variegata*	35	NA	38	*Hymenodictyon excelsum*	70	NA
11	*Bischofia javanica*	35	http://www.invasive.org/weeds/asian/bischofia.pdf	39	*Largerstroemia parviflora*	130	Troup, 1921, p595
12	*Bombax ceiba*	180	Troup, 1921, p135	40	*Lannea coromandelica*	70	NA
13	*Bridelia retusa*	16	NA	41	*Litsea monopetala*	45	NA
14	*Buchanania latifolia*	100	NA	42	*Mallotus philippensis*	22	NA
15	*Butea monosperma*	70	Troup, 1921, p257	43	*Myrsine semiserrata*	45	NA
16	*Careya arborea*	40	NA	44	*Phyllanthus emblica*	25	NA
17	*Casearia graveoles*	30	NA	45	*Pterocarpus marsupium*	75	Troup, 1994, p266
18	*Cassia fistula*	60	http://www.rngr.net/Publications/ttsm/Folder.2003-07-11.4726/PDF.2003-12-03.2733/file	46	*Randia dumetorum*	15	NA
19	*Cassine glauca*	80	NA	47	*Schleichera oleosa*	75	NA
20	*Carpesium nepalense*	25	NA	48	*Semecarpus anacardium*	30	Troup, 1994, p237
21	*Cedrela toona*	100	Jackson, 1994, p 732	*49*	*Shorea robusta*	250	Troup, 1994, p58 and Jackson, 1994, p714
22	*Cleistocalyx operculatus*	60	NA	*50*	*Syzygium cumini*	50	NA
23	*Cornus oblonga*	40	NA	*51*	*Terminalia alata*	180	Jackson, 1994, p725
24	*Dalbergia latifolia*	150	Troup, 1921, p318	52	*Terminalia bellirica*	97	Troup, 1994, p507
25	*Dalbergia sissoo*	75	Troup, 1921, p294	53	*Terminalia chebula*	75	www.disabled-world.comartman/publish
26	*Desmodium oojeinense*	80	NA	54	*Trewia nudiflora*	35	NA
27	*Dillenia pentagyna*	75	Troup, 1921, p3	55	*Xeromphis utiginosa*	10	NA
28	*Diospyros malabarica*	35	NA				

Note :

- Serial numbers: 1, 4, 7, 13, 30, 31, 35, 37, 41, 42, 43, 44, 47, 50, 55 (Researcher's personal experience)
- Serial numbers: 8, 10, 14, 16, 23, 26, 28, 29, 32, 33, 35, 36, 54 (Personal communication with Dr. R. Gyawali)
- Serial numbers: 2, 17, 19, 20, 22, 34, 38, 40, 46 (Field consultation)

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Table 4.11: Maximum height (H_{max}) of sal forest species

SN	Species	H_{max} (cm)	Information colectecd sources
1	*Acacia catechu*	2300	http://en.wikipedia.org/wiki/Acacia_catechu
2	*Actinodaphne angusifolia*	1600	NA
3	*Adina cordifolia*	4000	Troup, 1921, p 616 and Jackson, 1994, p363
4	*Aegle marmelos*	1300	Troup, 1921, p167
5	*Albizia lebbeck*	1800	http://en.wikipedia.org/wiki/Albizia_lebbeck
6	*Anogeissus latifolius*	2500	Troup, 1921, p543
7	*Anthocephalus chinensis*	2000	NA
8	*Aporusa octandra*	1800	NA
9	*Bauhinia purpurea*	1700	http://en.wikipedia.org/wiki/Bauhinia -purpure
10	*Bauhinia variegata*	1400	NA
11	*Bischofia javanica*	1800	http://www.invasive.org/weeds/asian/bischofia.pdf
12	*Bombax ceiba*	4000	Troup, 1921, p135
13	*Bridelia retusa*	800	NA
14	*Buchanania latifolia*	2000	NA
15	*Butea monosperma*	1500	NA
16	*Careya arborea*	1500	http://en.wikipedia.org/wiki/Careya_arborea
17	*Casearia graveoles*	1200	NA
18	*Cassia fistula*	1500	http://www.rngr.net/Publications/ttsm/Folder.2003-07-11.4726/PDF
19	*Cassine glauca*	2200	NA
20	*Carpesium nepalense*	1500	NA
21	*Cedrela toona*	2700	Jackson, 1994, p732
22	*Cleistocalyx operculatus*	2400	NA
23	*Cornus oblonga*	2000	NA
24	*Dalbergia latifolia*	4000	Jackson, 1994, p481
25	*Dalbergia sissoo*	3000	Troup, 1921, p294
26	*Desmodium oojeinense*	2500	NA
27	*Dillenia pentagyna*	2200	Troup,1921, p3
28	*Diospyros malabarica*	1400	NA
29	*Duabanga grandiflora*	3000	NA
30	*Ehretia wallichiana*	1000	NA
31	*Ficus beghalensis*	3000	http://www.aucegypt.edu/support/campaign/trees.htm
32	*Ficus benjamina*	2500	NA
33	*Garuga pinnata*	2700	NA
34	*Glochidion velutinum*	1500	NA
35	*Grewia optiva*	2200	NA
36	*Gmelina arborea*	3000	Jackson, 1994, p572
37	*Holarrhena pubescens*	1000	NA
38	*Hymenodictyon excelsum*	1800	NA
39	*Largerstroemia parviflora*	3000	Troup, 1921, p595
40	*Lannea coromandelica*	2500	NA
41	*Litsea monopetala*	1400	NA
42	*Mallotus philippensis*	1500	NA
43	*Myrsine semiserrata*	2400	NA
44	*Phyllanthus emblica*	1800	http://en.wikipedia.org/wiki/Phyllanthus_emblica
45	*Pterocarpus marsupium*	3100	Troup,1994, p266
46	*Randia dumetorum*	800	NA
47	*Schleichera oleosa*	2500	NA
48	*Semecarpus anacardium*	1000	Troup, 1994, p237
49	*Shorea robusta*	5500	Troup, 1994, p58 and Jackson, 1994, p714
50	*Syzygium cumini*	2000	http://www.fleppc.org/ID_book/syzygium%20cumini.pdf
51	*Terminalia alata*	3000	Jackson, 1994, p725
52	*Terminalia bellirica*	3700	Troup, 1994, p507
53	*Terminalia chebula*	2200	www.disabled-world.comartman/publish
54	*Trewia nudiflora*	1400	NA
55	*Xeromphis utiginosa*	800	NA

Note:

- Serial numbers: 7, 13, 22, 30, 37 , 41, 42, 43, 47,55 (Researcher's personal experience)
- Serial numbers: 8, 10, 14, 16, 23, 26, 28, 29, 32, 33, 35, 54 (Personal communication with Dr. R. Gyawali)
- Serial numbers: 2, 15, 17, 19, 20, 34, 38, 40, 46 (Field consultation)

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(b) Maximum diameter increment (∂D_{max})

Maximum diameter increments (∂D_{max}) of the species were not available in the references due to lack of such types of species specific growth and yield related long durable past researches in Nepal. Therefore, derivation from other known value was only the option to determine this parameter. Different methods were used to determine the species specific value of ∂D_{max}. Periodic and yearly diameter growth data and tables of the different species from different sources (as mentioned in section 4.2.2.1) were gathered and then analyzed to determine ∂D_{max} value. Furthermore, ∂D_{max} values of many species were also determined through using available any single year's diameter or height records. In the calculation process, for all the species yearly diameter status, height status, current year's diameter increment and mean annual diameter growth were computed and all the results are presented in tabular form (see example of *Acacia catechu* in Appendix-I) known as growth table.

The details calculation process was as follows: Initial diameter for all the species was fixed at 1.0 cm diameter. Height of the tree for the given year was computed by using the formule from Chapter 2 (equations 7.0, 7.1 and 7.2). Diameter increment for the given year was computed through optimum growth equation 1.1 of Chapter 2. Diameter of the following year was fixed by adding current year's diameter and diameter increment in current year. For example, diameter of the tree in year 2 equals to 1.0 cm plus diameter increment in year one. In the computation, ∂D_{max} was adjusted in such a way that the computed diameter of the given year matched with collected one. In the process at first ∂D_{max} is randomly choosen, then after the trial for several times, it will facilitate to match with particular year's diameter growth value. This is because of the reason that D_{max} and H_{max} were fixed for the given species and only ∂D_{max} was the variable to adjust the given years growth information. But in few cases D_{max} and H_{max} were also manipulated together with ∂D_{max}, while diameter and height of given growth were not matching. Adjustment and determination of ∂D_{max} of the particular species had several other objectives, such as: computing G value, adjusting given growth record and computation of Age_{max}. Magnitude of ∂D_{max} obtained from above process are presented in Table 4.12 and method of computation is also illustrated in Appendix-I.

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(c) Maximum age (Age_{max})

The maximum age (Age_{max}) of most species was chosen from their own growth table prepared in Section 4.2.2.1(b). The specific year was selected for the maximum age of the species by adopting Botkin's assumption of 2/3 of D/D_{max} reached at 1/2 Age_{max} (Botkin, 1993). Age_{max} for few other species were computed last growth point (zero growth method)[5]. Computation process of Age_{max} is illustrated in Appendix-J (for *Anogeissus latifolius)* to make further clarification. Age_{max} of all the species gained from computation are present in Table 4.12. Last column of the table includes the guiding information used in computation of ∂D_{max} and Age_{max}.

Table 4.12: ∂D_{max} and Age_{max} of sal forest species

SN	Species	∂D_{max}	Age_{max}	Guiding data and sources of information
1	*Acacia catechu*	1.4	117	Growth table was prepared with the help of height and diameter was collected from Jackson, 1994, p 343. Age_{max} was considered at the year when its diameter reaches D_{max} level and height reaches at H_{max} also called zero growth because then after no more growth found.
2	*Actinodaphne angusifolia*	0.3	264	Growth data were not available. Age_{max} was computed based on concept of 2/3 of D/D_{max} is reaches in year ½ of Age_{max} (Botkin's concept).
3	*Adina cordifolia*	0.9	428	Growth table was prepared with the help of given mean DBH increment value that was collected from Troup, 1921, p 616. Age_{max} was computed based on Botkin's concept.
4	*Aegle marmelos*	0.4	178	Growth table was prepared with the help of two periodic growth data year 10 and year 20 from Troup, 1921, p 170. Age_{max} was computed based on Botkin's concept.
5	*Albizia lebbeck*	1.4	117	Growth table was prepared with the help of 30 months growth data was note from Jackson, 1994, p378. Age_{max} was computed based on zero growth concepts.
6	*Anogeissus latifolius*	1.5	108	Growth table was prepared with the help of 15 yrs height and diameter record from Jackson, 1994, p392. Age_{max} was computed based on Botkin's concept.
7	*Anthocephalus chinensis*	3.5	27	Growth table was prepared with the help 30 month's growth data from Jackson, 1994, p393. Age_{max} was computed based on Botkin's concept.
8	*Aporusa octandra*	0.3	232	Growth data were not available. Age_{max} was computed based on Botkin's concept.
9	*Bauhinia purpurea*	0.6	88	Growth table was prepared with the help of one periodic growth data was recorded from Jackson, 1994, p429 and p 431. Age_{max} was computed based on Botkin's concept.
10	*Bauhinia variegata*	0.6	102	Growth table was prepared with the help of given height for one singular yearsrecorded from Jackson, 1994, p432. Age_{max} was computed based on Botkin's concept.
11	*Bischofia javanica*	0.5	120	Growth data were not available. Age_{max} was computed based on Botkin's concept.

[5] The year when the diameter of the tree reachs at D_{max} and height reaches at H_{max}. After this year no more growth in diameter and height of the species, therefore it is also called zero growth method.

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Table 4.12: ∂D_{max} and Age_{max} of sal forest species (cont.)

SN	Species	∂D_{max}	Agemax	Guiding data and sources of information
12	*Bombax ceiba*	2.4	132	Growth table was prepared with the help of two periodic growth data year 10 and year 20 was collected from Jackson, 1994, p441. Age_{max} was computed based on Botkin's concept.
13	*Bridelia retusa*	0.4	65	Growth data were not available. Age_{max} was computed based on Botkin's concept.
14	*Buchanania latifolia*	0.8	226	Growth table was prepared with the help periodic growth data and they were collected from Troup, 1921, p242. Age_{max} was computed based on Botkin's concept.
15	*Butea monosperma*	0.4	320	Growth table was prepared based on 8th year's growth data that was collected from Troup, 1921, p264. Age_{max} was computed based on Botkin's concept.
16	*Careya arborea*	0.2	350	Growth data were not available. Age_{max} was computed based on Botkin's concept.
17	*Casearia graveoles*	0.1	522	Growth data were not available. Age_{max} was computed based on Botkin's concept.
18	*Cassia fistula*	1.2	92	Periodic growth data and mean annual diameter increment data from Troup, 1921, p336. Age_{max} was computed based on Botkin's concept.
19	*Cassine glauca*	0.4	352	Growth data were not available. Age_{max} was computed based on Botkin's concept.
20	*Carpesium nepalense*	0.3	142	Growth data were not available. Age_{max} was computed based on Botkin's concept.
21	*Cedrela toona*	2	90	Growth table was prepared with the help of single years growth data that was collected from Troup,1921, p199. Age_{max} was computed based on Botkin's concept.
22	*Cleistocalyx operculatus*	0.7	150	Growth data were not available. Age_{max} was computed based on Botkin's concept.
23	*Cornus oblonga*	0.4	172	Growth data were not available. Age_{max} was computed based on Botkin's concept.
24	*Dalbergia latifolia*	1.4	188	Growth table was prepared with the help of periodic growth information available from Jackson 1994, pp 481 Age_{max} was computed based on Botkin's concept.
25	*Dalbergia sissoo*	2.5	70	Growth table was prepared with the help of periodic growth information that was abialable on Jackson 1994, p488. Age_{max} was computed based on Botkin's concept.
26	*Desmodium oojeinense*	0.4	350	Growth data were not available. Age_{max} was computed based on Botkin's concept.
27	*Dillenia pentagyna*	0.5	264	Growth table was prepared with the help of periodic growth information that was abialable on Troup,1921, p4. Age_{max} was computed based on Botkin's concept.
28	*Diospyros malabarica*	0.5	124	Growth data were not available. Age_{max} was computed based on Botkin's concept.
29	*Duabanga grandiflora*	0.4	344	Growth data were not available. Age_{max} was computed based on Botkin's concept.
30	*Ehretia wallichiana*	0.3	148	Growth data were not available. Age_{max} was computed based on Botkin's concept.
31	*Ficus beghalensis*	0.6	290	Growth table was prepared based on avialble height of one particular age from Jackson 1994, p553. Age_{max} was computed based on Botkin's concept.
32	*Ficus benjamina*	0.3	344	Growth data were not available. Age_{max} was computed based on Botkin's concept.
33	*Garuga pinnata*	1.4	70	Growth table was prepared based on avialble height and diameter data for particular year from Troup, 1921, p167. Age_{max} was computed based on Botkin's concept.
34	*Glochidion velutinum*	0.3	265	Growth data were not available. Age_{max} was computed based on Botkin's concept.
35	*Grewia optiva*	0.8	108	Growth data were not available. Age_{max} was computed based on Botkin's concept.
36	*Gmelina arborea*	0.5	240	Growth data were not available. Age_{max} was computed based on Botkin's concept.

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Table 4.12: ∂D_{max} and Age_{max} of sal forest species (cont.)

SN	Species	∂D_{max}	Agemax	Guiding data and sources of information
37	*Holarrhena pubescens*	0.6	92	Growth data were not available. Age_{max} was computed based on Botkin's concept.
38	*Hymenodictyon excelsum*	0.4	312	Growth data were not available. Age_{max} was computed based on Botkin's concept.
39	*Largerstroemia parviflora*	1.8	266	Growth table was prepared based on avialble periodic data of diameter and height growth from Troup, 1921, p598. Agemax was computed by zero growth concepts.
40	*Lannea coromandelica*	0.7	174	Growth data were not available. Age_{max} was computed based on Botkin's concept.
41	*Litsea monopetala*	1.5	56	Growth table was prepared based on avialble height and diameter growth records of different ages from Jackson, 1994, p606. Age_{max} was computed based on Botkin's concept.
42	*Mallotus philippensis*	0.3	122	Growth data were not available. Age_{max} was computed based on Botkin's concept.
43	*Myrsine semiserrata*	0.4	192	Growth data were not available. Age_{max} was computed based on Botkin's concept.
44	*Phyllanthus emblica*	0.7	132	Growth data were not available. Age_{max} was computed based on Botkin's concept.
45	*Pterocarpus marsupium*	0.6	216	Growth table was prepared based on avialble periodic data of diameter and height growth from Troup, 1921, p266.
46	*Randia dumetorum*	0.07	356	Growth data were not available. Age_{max} was computed based on Botkin's concept.
47	*Schleichera oleosa*	0.3	434	Growth data were not available. Age_{max} was computed based on Botkin's concept.
48	*Semecarpus anacardium*	0.4	136	Growth table was prepared based on avialble periodic data of diameter and height growth from Troup, 1921, p237. Age_{max} was computed based on Botkin's concept.
49	*Shorea robusta*	2.9	340	Growth table was prepared based on avialble periodic data of diameter and height growth from Olavi Rautiainen, 1998. Age_{max} was computed based on Botkin's concept.
50	*Syzygium cumini*	1.2	74	Growth table was prepared based on avialble periodic data of diameter and height growth from Jackson, 1994, p716. Age_{max} was computed based on Botkin's concept.
51	*Terminalia alata*	1.0	308	Growth table was prepared based on avialble periodic data of diameter and height growth from Jackson, 1994, p725. Age_{max} was computed based on Botkin's concept.
52	*Terminalia bellirica*	1.3	266	Growth table was prepared based on avialble periodic data of diameter and height growth from Jackson,1994, p728. Agemax was computed based on Botkin's concept.
53	*Terminalia chebula*	0.8	166	Growth table was prepared based on avialble periodic data of diameter and height growth from Troup,1921, p514. Age_{max} was computed based on Botkin's concept.
54	*Trewia nudiflora*	0.9	70	Growth table was prepared based on avialble periodic data of diameter and height growth from Jackson, 1994, p736. Age_{max} was computed based on Botkin's concept.
55	*Xeromphis utiginosa*	0.1	154	Growth data were not available. Age_{max} was computed based on Botkin's concept.

Note:
Growth information of following 27 species was not found in the references. Maximum diameter increment (∂D_{max}**)** for these species were collected from following sources.

Sources of ∂D_{max} :

- Serial numbers: 13, 22, 30, 37, 42, 43, 44, 47, 55 (Researcher's personal experience)
- Serial numbers: 8,16, 23, 26, 28, 29, 32, 35 (Personal communication with Dr. R. Gyawali)
- Serial numbers: 2, 11, 17, 19, 20, 34, 36, 38, 40, 46 (Field consultation)

Then, growth tables for all the species were prepared as descried in Section 4.2.2.1 (b)

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(d) Shade tolerance level

Three types of shade tolerance level information were collected as per the requirement of the model structure. Shade tolerant level information were mostly collected from text books "Principle and practice of silviculture, Khanna, 1993" and "The silviculture of Indian trees, volumes I, II and III, RS Troup,1921)". About 50% shade tolerant information was collected from above two sources. Expert consultation, discussion in the field, and researcher's personal experience were also used to execute category of the shade tolerant for the rest of the species. Percentage coverage by each species is illustrated in Figure 4.4. Maximum numbers of species were found in the intermediate level class (24 species, 44%), second rank of species were in shade tolerant level (16 species, 29%) and least number of species were in shade intolerant level (15 species, 27%). Shade tolerant level information of all species and their basis of sources are present in Table 4.13.

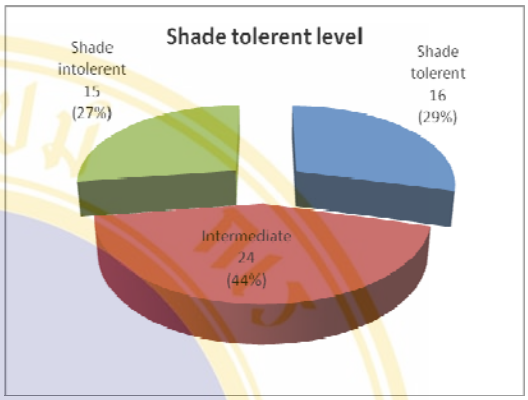

Figure 4.5: Shade tolerant status

Table 4.13: Shade tolerant category of tree species of the sal forest

SN	Species	Shade tolerant level	Information collected	Category for model
1	*Acacia catechu*	Strong light demander	Jackson, 1994, p340	Shade intolerent
2	*Actinodaphne angusifolia*	Light demander	NA	Shade intolerent
3	*Adina cordifolia*	Intermediate	NA	Intermediate
4	*Aegle marmelos*	Moderate shade tolerant	Troup, 1921, p167	Shade tolerent
5	*Albizia lebbeck*	Moderate light demander	Jackson, 1994, p377	Shade intolerent
6	*Anogeissus latifolius*	Strong light demander	Jackson, 1994, p391	Shade intolerent
7	*Anthocephalus chinensis*	Light demander	Troup, 1921 , p615	Shade intolerent
8	*Aporusa octandra*	Shade tolerant	NA	Shade tolerent
9	*Bauhinia purpurea*	Moderate shade tolerant	Jackson, 1994, p429	Shade tolerent
10	*Bauhinia variegata*	Intermediate	NA	Intermediate
11	*Bischofia javanica*	Shade tolerent	NA	Shade tolerent
12	*Bombax ceiba*	Strong light demander	Jackson, 1994, p439	Shade intolerent
13	*Bridelia retusa*	Moderate shade tolerant	Jackson, 1994, p445	Shade tolerent
14	*Buchanania latifolia*	Intermediate	Troup, 1921, p242	Intermediate
15	*Butea monosperma*	Fairly shade bearer	Troup, 1921, p260	Shade tolerent
16	*Careya arborea*	Shade tolerant	LS Khana, 1993, p51	Shade tolerent
17	*Casearia graveoles*	Intermediate	NA	Intermediate
18	*Cassia fistula*	Intermediate	Jackson,1994, p453 and Troup,1921, p367	Intermediate

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Table 4.13: Shade tolerant category of tree species of the sal forest (cont.)

SN	*Species*	Shade tolerant level	Information collected	Category for model
19	*Cassine glauca*	Intermediate	NA	Intermediate
20	*Carpesium nepalense*	Intermediate	NA	Intermediate
21	*Cedrela toona*	Moderate shade tolerant	Troup, 1921, p199 and Khanna, 1993, p51	Shade tolerent
22	*Cleistocalyx operculatus*	Shade tolerant	NA	Shade tolerent
23	*Cornus oblonga*	Intermediate	NA	Intermediate
24	*Dalbergia latifolia*	Intermediate	Khanna , 1993, p51	Intermediate
25	*Dalbergia sissoo*	Strong light demander	Jackson, 1994, p484 and Troup,1921, p300	Shade intolerent
26	*Desmodium oojeinense*	Moderate shade tolerant	NA	Shade tolerent
27	*Dillenia pentagyna*	Intermediate	Troup,1921, p 3	Shade tolerent
28	*Diospyros malabarica*	Intermediate	NA	Intermediate
29	*Duabanga grandiflora*	Intermediate	NA	Intermediate
30	*Ehretia wallichiana*	Shade tolerant	NA	Shade tolerent
31	*Ficus beghalensis*	Moderate light demander	Jackson, 1994, p552	Shade tolerent
32	*Ficus benjamina*	Shade tolerant	NA	Shade tolerent
33	*Garuga pinnata*	Strong light demander	Troup,1921, p176	Shade intolerent
34	*Glochidion velutinum*	Intermediate	NA	Intermediate
35	*Grewia optiva*	Light demander	Jackson, 1994, p576	Shade intolerent
36	*Gmelina arborea*	Light demander	Jackson, 1994, p572	Shade intolerent
37	*Holarrhena pubescens*	Intermediate	NA	Intermediate
38	*Hymenodictyon excelsum*	Intermediate	NA	Intermediate
39	*Largerstroemia parviflora*	Light demander	Jackson, 1994, p591	Shade intolerent
40	*Lannea coromandelica*	Light demander	Jackson, 1994, p593	Shade intolerent
41	*Litsea monopetala*	Moderate shade tolerant	Jackson, 1994, p605	Intermediate
42	*Mallotus philippensis*	Shade tolerant	Khanna, 1993, p51	Shade tolerent
43	*Myrsine semiserrata*	Intermediate	NA	Intermediate
44	*Phyllanthus emblica*	Strong light demander	Jackson,1994, p623	Shade intolerent
45	*Pterocarpus marsupium*	Shade bearer	Troup,1994, p270 and Khanna 1993, p51	Intermediate
46	*Randia dumetorum*	Intermediate	NA	Intermediate
47	*Schleichera oleosa*	Shade tolerant	Khanna 1993, p51	Shade tolerent
48	*Semecarpus anacardium*	Moderate shade bearer	Troup, 1994, p237	Shade tolerent
49	*Shorea robusta*	Strong light demander	Troup, 1994, p58 and Jackson, 1994, p714	Shade intolerent
50	*Syzygium cumini*	Intermediate	Jackson,1994, p716	Intermediate
51	*Terminalia alata*	Moderate shade tolerant	Troup,1921, p520	Intermediate
52	*Terminalia bellirica*	Light demander	Troup,1994, p509	Shade intolerent
53	*Terminalia chebula*	Moderate shade tolerant	Jackson,1994, p716	Intermediate
54	*Trewia nudiflora*	Moderate shade tolerant	Jackson , 1994, p735	Intermediate
55	*Xeromphis utiginosa*	Shade tolerant	NA	Shade tolerent

Note:
Shade tolerant level information for the following trees were collected from:

- Serial numbers: 10, 22, 30, 37, 43, 55 (Researcher's personal experience)
- Serial numbers: 3, 8, 23, 26, 28, 29, 32 (Personal communication with Dr. R. Gyawali)
- Serial numbers: 2, 11, 17, 19, 20, 34, 38, 46 (Field consultation)

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(e) **Growth factor (G)**

Growth factor (G) for all the species was computed after computation of ∂D_{max}, D_{max} and H_{max}, by using the formula $G_{\partial Dmax} \cong 5H_{max}(\frac{\partial D_{max}}{D_{max}})$ (adopted by Botkin, 1993). Highest value of G was found 700 which belong to *Anthocephalus chinensis*, a shade intolerant species. Similarly, second highest value was 500 that belongs to *Dalbergia sissoo*. It is also a shade intolerant pioneer species for riverine succession. Lowest value of G was 19 belongs to *Randia dumetorum* an intermediate shade tolerant l species and this tree is smaller in size. At the shade tolerant level, maximum of G value was 270 belongs to *Cedrela toona* a large sized climax stage tree. It shows G values of shade intolerant trees were found higher than other two classes. Other two coefficients (b_2 and b_3) were also computed for all the species. G, b_2 and b_3 values are presented in Appendix-K.

4.2.2.1 Birth related parameters

New seedling recruitment in the stand is determined by four major parameters SPSP: (a) seed phenology, (b) seed longevity, (c) seed dispersal, and (d) type of soil required for seedling establishment and they are mentioned in the following sections respectively.

(a) Seed phenology (p_1)

Model consists of two types of seed phenology, therefore species were categorized into two groups in terms of phenology. Species that gives fertile seeds every year was named uniform or regular otherwise irregular. Sources of information collection were same as described in growth related parameters. Unfortunately, only 20% species' information on seed phenology were found in the prescribed references and rest 80% were classified based on expert's option, researcher's personal experience and field consultation. Seed phenology of the species is presented in Table 4.14.

Table 4.14: Seed phenology of tree species of the sal forest

SN	Species	Seed phenology	Sources	SN	Species	Seed phenology	Sources
1	*Acacia catechu*	Regular	Jackson, 1994, p341	3	*Adina cordifolia*	Irregular	NA
2	*Actinodaphne angusifolia*	Irregular	NA	4	*Aegle marmelos*	Regular	NA

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Table 4.14: Seed phenology of tree species of the sal forest (cont.)

SN	Species	Seed phenology	Sources	SN	Species	Seed phenology	Sources
5	*Albizia lebbeck*	Regular	NA	31	*Ficus beghalensis*	Regular	NA
6	*Anogeissus latifolius*	Regular	Jackson, 1994, p391	32	*Ficus benjamina*	Regular	NA
7	*Anthocephalus chinensis*	Regular	NA	33	*Garuga pinnata*	Irregular	NA
8	*Aporusa octandra*	Irregular	NA	34	*Glochidion velutinum*	Irregular	NA
9	*Bauhinia purpurea*	Regular	NA	35	*Grewia optiva*	Irregular	Jackson, 1994, p576
10	*Bauhinia variegata*	Regular	NA	36	*Gmelina arborea*	Irregular	NA
11	*Bischofia javanica*	Irregular	NA	37	*Holarrhena pubescens*	Irregular	NA
12	*Bombax ceiba*	Irregular	Troup, 1921, p144	38	*Hymenodictyon excelsum*	Irregular	NA
13	*Bridelia retusa*	Irregular	NA	39	*Largerstroemia parviflora*	Regular	Jackson,1994, p591
14	*Buchanania latifolia*	Irregular	NA	40	*Lannea coromandelica*	Irregular	NA
15	*Butea monosperma*	Regular	NA	41	*Litsea monopetala*	Regular	Jackson, 1994, p605
16	*Careya arborea*	Irregular	NA	42	*Mallotus philippensis*	Regular	NA
17	*Casearia graveoles*	Irregular	NA	43	*Myrsine semiserrata*	Irregular	NA
18	*Cassia fistula*	Irregular	NA	44	*Phyllanthus emblica*	Regular	Jackson, 1994, p623
19	*Cassine glauca*	Irregular	NA	45	*Pterocarpus marsupium*	Irregular	NA
20	*Carpesium nepalense*	Irregular	NA	46	*Randia dumetorum*	Irregular	NA
21	*Cedrela toona*	Irregular	NA	47	*Schleichera oleosa*	Irregular	NA
22	*Cleistocalyx operculatus*	Irregular	NA	48	*Semecarpus anacardium*	Irregular	NA
23	*Cornus oblonga*	Irregular	NA	49	*Shorea robusta*	Irregular	Jackson, 1994, p714
24	*Dalbergia latifolia*	Irregular	NA	50	*Syzygium cumini*	Irregular	Jackson, 1994, p716
25	*Dalbergia sissoo*	Regular	Jackson, 1994, p484	51	*Terminalia alata*	Irregular	Troup,1921, p519
26	*Desmodium oojeinense*	Irregular	NA	52	*Terminalia bellirica*	Irregular	NA
27	*Dillenia pentagyna*	Irregular	NA	53	*Terminalia chebula*	Irregular	NA
28	*Diospyros malabarica*	Regular	NA	54	*Trewia nudiflora*	Regular	NA
29	*Duabanga grandiflora*	Irregular	NA	55	*Xeromphis utiginosa*	Irregular	NA
30	*Ehretia wallichiana*	Irregular	NA				

Note: Sources of seed phenology charecteristics of the "NA" were as follows.

- Serial numbers: 7, 13, 22, 30, 31 (Researcher's personal experience)
- Serial numbers: 4, 5, 9, 10, 16, 23, 24, 26, 52, 53 (Personal communication with Dr. R. Gyawali)
- Serial numbers: 2, 3, 8, 11, 14, 15, 17,18, 19, 20, 21, 27, 28, 29, 32, 33, 34, 36, 37, 38, 40, 42, 43, 45, 46, 47, 48, 46, 54, 55 (Field consultation)

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(b) Seed longevity (p_2)

Model structure consists of four types of seed longevity, therefore species were categorized in four groups to provide the input for the model's necessity. They were: very short- if the seed germination capacity viable is not longer than 6 weeks, short- if germination capacity goes to 6 weeks to 3 months, medium- if it goes to 3 months to one year and long- if seed is viable more than one year for germination. Sources of information collectioned were same as described in growth related parameters. More than 50% of the information was recorded from available references. Seed longevity characteristics of all the species are presented in Table 4.15.

Table 4.15: Seed longevity (p_2) of tree species of sal forest

SN	Species	P2	Source	SN	Species	P2	Source
1	*Acacia catechu*	Medium	Jackson, 1994, p341	21	*Cedrela toona*	Very short	NA
2	*Actinodaphne angusifolia*	Short	NA	22	*Cleistocalyx operculatus*	Medium	NA
3	*Adina cordifolia*	Medium	Jackson, 1994, p364	23	*Cornus oblonga*	Short	NA
4	*Aegle marmelos*	Medium	NA	24	*Dalbergia latifolia*	Long	Jackson 1994, p481
5	*Albizia lebbeck*	Long	Jackson, 1994, p377	25	*Dalbergia sissoo*	Long	Troup, 1921, p303
6	*Anogeissus latifolius*	Medium	Jackson, 1994, p391	26	*Desmodium oojeinense*	V. Short	NA
7	*Anthocephalus chinensis*	Medium	NA	27	*Dillenia pentagyna*	Long	Troup, 1921, p4
8	*Aporusa octandra*	Medium	NA	28	*Diospyros malabarica*	Medium	NA
9	*Bauhinia purpurea*	Long	Jackson, 1994, p431	29	*Duabanga grandiflora*	Very Short	NA
10	*Bauhinia variegata*	Short	Jackson, 1994, p432	30	*Ehretia wallichiana*	Short	NA
11	*Bischofia javanica*	Short	NA	31	*Ficus beghalensis*	Medium	Jackson, 1994, p552
12	*Bombax ceiba*	Medium	Jackson, 1994, p439	32	*Ficus benjamina*	V.Short	NA
13	*Bridelia retusa*	Medium	Jackson, 1994, p445	33	*Garuga pinnata*	Medium	Jackson, 1994, p568
14	*Buchanania latifolia*	Very short	Troup, 1921, p242	34	*Glochidion velutinum*	Very Short	NA
15	*Butea monosperma*	Medium	Troup, 1921, p263	35	*Grewia optiva*	Long	Jackson, 1994, p576
16	*Careya arborea*	Short	NA	36	*Gmelina arborea*	Long	Jackson, 1994, p572
17	*Casearia graveoles*	Medium	NA	37	*Holarrhena pubescens*	Short	NA
18	*Cassia fistula*	Long	NA	38	*Hymenodictyon excelsum*	Medium	NA
19	*Cassine glauca*	Medium	NA	39	*Largerstroemia parviflora*	Short	Jackson,1994, p594
20	*Carpesium nepalense*	Short	NA	40	*Lannea coromandelica*	Short	Jackson, 1994, p593

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Table 4.15: Seed longevity (p_2) of tree species of sal forest (cont.)

SN	Species	P2	Source	SN	*Species*	P2	Source
41	*Litsea monopetala*	Medium	Jackson, 1994, p605	49	*Shorea robusta*	Very short	Troup, 1994, p58 &Jackson, 1994, p714
42	*Mallotus philippensis*	Short	NA	50	*Syzygium cumini*	V.short	Jackson,1994, p716
43	*Myrsine semiserrata*	Medium	NA	51	*Terminalia alata*	Medium	Jackson, 1994, p725
44	*Phyllanthus emblica*	Medium	Jackson, 1994, p623	52	*Terminalia bellirica*	Long	NA
45	*Pterocarpus marsupium*	Short	Troup, 19994, p270	53	*Terminalia chebula*	Short	Troup, 1994, p515
46	*Randia dumetorum*	Medium	NA	54	*Trewia nudiflora*	V.short	Jackson, 1994, p735
47	*Schleichera oleosa*	Short	NA	55	*Xeromphis utiginosa*	Short	NA
48	*Semecarpus anacardium*	Medium	Troup, 1994, p237				

Note: Seed longivity of the following species was collected form following sources.

- Serial numbers: 42, 43, 47 (Researcher's personal experience)
- Serial numbers: 4, 16, 23, 26, 32, 52, 4, 16, 23, 26, 32, 52 (Personal communication with Dr. R. Gyawali)
- Serial numbers: 2, 7, 11, 17, 18, 19, 20, 21, 28, 29, 30, 34, 37, 38, 45, 46, 55 (Field consultation)

(c) Seed dispersal

Model structure only consists three categories of seed dispersal agents: wind, bird and gravity. No any species were found to disperse seed by gravity in the study site. However, seed dispersal agents of the study site were found more than three category but they were summarized into three levels as per model's requirement. For example, few species in the study site found dispersal by water but this sub-component is absence in the model. Similarly, some other species were found to disperse seed by large mammals but this part is also absent in the model. Most of the species specific seed dispersal information was found in above pescribed three text books. Seed dispersal information of rest of the species was collected through same methodology prescribed in seed phenology and seed longevity.

Table 4.16: Species seed dispersal agests in sal forest

SN	Species	Dispersal agent	Sources
1	*Acacia catechu*	Wind	Jackson, 1994, p341
2	*Actinodaphne angusifolia*	Bird	NA
3	*Adina cordifolia*	Wind	Troup, 1921, p619
4	*Aegle marmelos*	Bird	Troup, 1921, p167
5	*Albizia lebbeck*	Wind	Jackson, 1994, p371
6	*Anogeissus latifolius*	Wind	Troup, 1921, p543 and Jackon, 1994, p391
7	*Anthocephalus chinensis*	Animal and bird	Troup, 1921, p 615

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Table 4.16: Species seed dispersal agests in sal forest (cont.)

SN	*Species*	Dispersal agent	Sources
8	*Aporusa octandra*	Bird	NA
9	*Bauhinia purpurea*	Wind	NA
10	*Bauhinia variegata*	Wind	NA
11	*Bischofia Javanica*	Bird	NA
12	*Bombax ceiba*	Wind	Jackson, 1994, p439
13	*Bridelia retusa*	Bird	NA
14	*Buchanania latifolia*	Bird	Troup, 1921, p242
15	*Butea monosperma*	Wind	NA
16	*Careya arborea*	Bird	NA
17	*Casearia graveoles*	Bird	NA
18	*Cassia fistula*	Large animals and birds	Jackson, 1994, p453
19	*Cassine glauca*	Bird	NA
20	*Carpesium nepalense*	Bird	NA
21	*Cedrela toona*	Wind and water	Troup, 1991, p 199
22	*Cleistocalyx operculatus*	Bird	NA
23	*Cornus oblonga*	Bird	NA
24	*Dalbergia latifolia*	wind	Jackson, 1994, p481
25	*Dalbergia sissoo*	Wind and water	Jackson, 1994, p484 and Troup, 1921, p303
26	*Desmodium oojeinense*	Bird	NA
27	*Dillenia pentagyna*	Bird and gravity	Troup, 1921, p3
28	*Diospyros malabarica*	Animal and gravity	NA
29	*Duabanga grandiflora*	Bird	NA
30	*Ehretia wallichiana*	Wind	NA
31	*Ficus beghalensis*	Bird	Jackson, 1994, p552
32	*Ficus benjamina*	Bird	NA
33	*Garuga pinnata*	Bird	Troup, 1921, p178
34	*Glochidion velutinum*	Bird	NA
35	*Grewia optiva*	Bird	Jackson,1994, p576
36	*Gmelina arborea*	Cattle /animal	Jackson,1994,p572
37	*Holarrhena pubescens*	Wind	NA
38	*Hymenodictyon excelsum*	Bird	NA
39	*Largerstroemia parviflora*	Wind	Jackson, 1994, p594
40	*Lannea coromandelica*	Wind	Jackson, 1994, p593
41	*Litsea monopetala*	Bird	NA
42	*Mallotus philippensis*	Bird	NA
43	*Myrsine semiserrata*	Bird	NA
44	*Phyllanthus emblica*	Bird and gravity	NA
45	*Pterocarpus marsupium*	Bird	NA
46	*Randia dumetorum*	Wind	NA
47	*Schleichera oleosa*	Bird	NA
48	*Semecarpus anacardium*	Bird	Troup, 1994, p 237
49	*Shorea robusta*	Wind	Troup, 1994, p58 and Jackson, 1994, p714
50	*Syzygium cumini*	Bird	Jackson, 1994, p716
51	*Terminalia alata*	Wind	Jackson, 1994, p725
52	*Terminalia bellirica*	Wind	Troup, 1994, p507 and Jackson, 1994, p728
53	*Terminalia chebula*	Wind	Troup, 1994, p514
54	*Trewia nudiflora*	Water and animal	Jackson, 1994, p735
55	*Xeromphis utiginosa*	Animal	NA

Note: Seed dispersal information for the following species was collected form following different sources.

- Serial numbers: 13, 41, 44 ,55 (Researcher's personal experience)
- Serial numbers: 23, 32, 42, 43 (Personal communication with Dr. R. Gyawali)
- Serial numbers: 2, 8, 9, 10, 11, 15, 16, 17, 19, 20, 22, 26, 28, 29, 30, 34, 37, 38, 45, 46, 47 (Field consultation)

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(d) Soil required for plant establishment

Model structure comprises of only two types of soil: mineral soil and raised soil. Species in the sal forest needs many different kinds of soil for their establishment and development but they are not included in the model structure. Therefore, the model does not provide the opportunity of putting all those collected varieties as inputs for the particular species because there are no such options. Due to this limitation, all types of soil were categorized in this way: the soils that were close with mineral were classified as mineral soil, if they were close with raised, then they were categorized as raised soil and the soil that does not tally with above two classes were categorized in non classes. Soil required information is present in Table 4.17.

Table 4.17: Types of soil required for tree species of sal forest

SN	*Species*	Type of soil required	Sources	Categorized for the model
1	*Acacia catechu*	Deposited alluvial soil in river belt	Jackson, 1994, p340	Mineral
2	*Actinodaphne angusifolia*	Moist loamy soil	NA	Mineral
3	*Adina cordifolia*	Open	Jackson, 1994, p364	Non
4	*Aegle marmelos*	Well drainage	Troup, 1921, p167	Non
5	*Albizia lebbeck*	Clay , loamy	Jackson, 1994, p377	Mineral
6	*Anogeissus latifolius*	Well drainage newly exposure soil	Jackson, 1994, p391	Raised
7	*Anthocephalus chinensis*	Deep alluvial soil	Jackson, 1994, p392	Mineral
8	*Aporusa octandra*	Moist loamy clay	NA	Mineral
9	*Bauhinia purpurea*	No special	Jackson, 1994, p429	Mineral
10	*Bauhinia variegata*	Well drainage ,no water logging	Jackson, 1994, p432	Non
11	*Bischofia javanica*	Clay	NA	Non
12	*Bombax ceiba*	Deep sandy alluvial	Jackson, 1994, p439	Mineral
13	*Bridelia retusa*	Moist loamy	NA	Non
14	*Buchanania latifolia*	Well drainage	Troup, 1921, p242	Non
15	*Butea monosperma*	No special	Troup, 1921, p263	Mineral
16	*Careya arborea*	Well drainage	NA	Mineral
17	*Casearia graveoles*	Mineral	NA	Mineral
18	*Cassia fistula*	Poor shadow soil	Jackson, 1994, p453 and Troup, 1921, p367	Non
19	*Cassine glauca*	Clay ,well drainage soil	NA	Non
20	*Carpesium nepalense*	Shadow soil	NA	Non
21	*Cedrela toona*	Deep moist	Troup, 1991, p199	Non
22	*Cleistocalyx operculatus*	Moist, shade soil	NA	Non
23	*Cornus oblonga*	Loamy soil	NA	Mineral
24	*Dalbergia latifolia*	Sandy loam soil	Jackson, 1994, p481	Mineral
25	*Dalbergia sissoo*	Alluvial soil	Jackson, 1994, p484 and Troup, 1921, p303	Mineral
26	*Desmodium oojeinense*	Well drainage high porous gravel soil	NA	Non

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Table 4.17: Types of soil required for tree species of sal forest (cont.)

SN	*Species*	Type of soil required	Sources	Categorized for the model
27	*Dillenia pentagyna*	Recently burned grassland soil	Troup, 1921, p4	Non
28	*Diospyros malabarica*	Dry clay soil	NA	Non
29	*Duabanga grandiflora*	Not special	NA	Non
30	*Ehretia wallichiana*	Moist loamy soil	NA	Mineral
31	*Ficus beghalensis*	Moist Loamy soil	Jackson, 1994, p552	Mineral
32	*Ficus benjamina*	Not specieal	NA	Non
33	*Garuga pinnata*	Dry soil	Troup, 1921, p176 and Jackson, 1994, p568	Non
34	*Glochidion velutinum*	Mineral soil	NA	Mineral
35	*Grewia optiva*	Verity of soil	Jackson, 1994, p576	Non
36	*Gmelina arborea*	Fertile and drainage soil	Jackson, 1994, p572	Mineral
37	*Holarrhena pubescens*	Well drainage sandy soil	NA	Non
38	*Hymenodictyon excelsum*	Sandy clay	NA	Mineral
39	*Largerstroemia parviflora*	Not special	Jackson, 1994, p594	Non
40	*Lannea coromandelica*	Sandy Loam upto high ph	Jackson, 1994, p593	Mineral
41	*Litsea monopetala*	Non special	Jackson, 1994, p605	Non
42	*Mallotus philippensis*	Moist sandy loam	NA	Non
43	*Myrsine semiserrata*	NA	NA	Non
44	*Phyllanthus emblica*	NA	NA	Non
45	*Pterocarpus marsupium*	Loose (not compact) fertile soil	Troup, 1994, p270	Non
46	*Randia dumetorum*	Moist soil	NA	Non
47	*Schleichera oleosa*	Dry soil	NA	Non
48	*Semecarpus anacardium*	Well drainage loamy soil	NA	Mineral
49	*Shorea robusta*	Well-drainage moist deep sandy loam with good sub soil drainage	Troup, 1994, p58	Non
50	*Syzygium cumini*	Moist soil	Jackson, 1994, p716	Non
51	*Terminalia alata*	Deep clay	Jackson, 1994, p725	Non
52	*Terminalia bellirica*	Good moisture supply soil	Jackson, 1994, p28	Non
53	*Terminalia chebula*	Deep rich alluvial soil	Troup, 1994, p515	Non
54	*Trewia nudiflora*	Moist soil	Jackson, 1994, p735	Non
55	*Xeromphis utiginosa*	Moist loamy soil	NA	Mineral

Note: Type of soil required for the following species was collected form following different sources.

- Serial numbers: 13, 44 ,55 (Researcher's personal experience)
- Serial numbers: 23, 32, 42, 43 (Personal communication with Dr. R. Gyawali)
- Serial numbers: 2, 8, 11, 15,16, 17, 19, 20, 22, 26, 28, 29, 30, 34, 37, 38, 46, 47, 48 (Field consultation)

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4.2.3 Determination of SISP

Determination of SISP was found more difficult than that SPSP due to lack of information. CNP in Nepal and the KIAMBRAM model developed site in Australia are located in the same sub tropical climatical zone. Forest types in Nepal related to study site is sub tropical decidious forest, whereas in Australia it is subtropical rain forest. Due to the similar climatic zone and somehow similar forest types, most of the site related parameters remain unchanged in this study. But some deterministic parameters collected from literature and expert consultation were only changed. Methods used for determination of different parameters of SISP and their values are described in sections: growth related SISP, birth related SISP and kill related SISP.

4.2.3.1 Growth related SISP

a) Light extinction coefficient

Light extinction coefficient (k) value in the KIAMBRAM model was used 0.375. Matthe and Pilbeam (2005) used 0.37 for k in Nepal's subtropical land in agro forestry field near to this study area is found and was used for re-parameterization process in this study due to lack of other reliable value recorded for natural forest area inside the National Park.

b) Maximum allowed basal area (SOILQ)

Maximum allowed basal area (SOILQ) component in the KIAMRAM model accounts the crowd competition for both moisture and nutrient from soil which is similar to the assumption of the JABOWA model (Roachanakanan, 2002). The application of the KIAMBRAM model to simulate succession in the mixed evergreen forests of the southern Cape, South Africa called OUTENIQUA model (Daalen and Shugart, 1989), also used the SOILQ value 160 m^2/ha. In this study, SOILQ value is changed from 160 m^2/ha to 130 m^2/ha because of the following reasons.

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(i) Soil condition of the study area was mostly gravel deposited: shorter thickness of top soil, thickness of A and B soil layers was shorter and comparatively less fertile. In such condition, root of the plants cannot reach in long depth. Very high level root competition will occurs within the very short depth. In Figure 4.5, fallen sal tree shows that it has shorter and dense root system. Such sites cannot control the higher density especially the bigger sized trees.

Figure 4.6: Fallen sal tree shows shorter root system

(ii) Characteristics of the sal forest is almost monoculture and mostly even aged stand (Troup, 1921), on the other hand sal is shade intolerant species, canopy mostly clustered near the tips. Due to these reasons, crown competition occurs at the top canopy level results poor density of the large size tree. Figure 4.6 shows observed mature dense forest but the calculation shows poor basal area.

Figure 4.7: Fully stock sal forest but not rich in basal area

(iii) Filed level observations had recognized above issues of poor production capacity of basal area and it was suggested that SOILQ value should be near to 130 m^2/ha. Therefore, 130 m^2/ha is chosen for this study. It indicates that the site can produce maximum basal area upto 130 m^2/ha. In this study, maximum observed basal area was only 49.56 m^2/ha but SOILQ value is still 2.5 times higher. Similar differences were also observed between SOILQ value and maximum observed basal area in the KIAMRAM model (Roachanakanan, 2002).

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4.2.3.2 Birth related SISP

Birth related structure, parameter and assumption of the KIAMBRAM model remains unchanged in this study because there was no opportunity to change this option in the provided model package. This model assumes that seed source for all 55 species is sufficient and intact. The model set the initial size of the plant approximately 1.27 cm DBH. Recruitments are applied as filter in the model as per their eligibility and stochastically. Probability of recruitment is fixed 1-20 numbers of seeding in a normal year and 1-600 in the Chablis year or when the leaf area index is less than 1 in the KIAMBRAM model.

4.2.3.3 Kill related SISP

Among the three responsible factors: (a) age of the plant, (b) event of Chablis (event of tree fall) and (c) suppression are responsible for tree killing in the model. The Chablis is special in the KIAMBRAM model whereas other two factors are common in most of the gap models. Probability of Chablis event was changed during the parameterization process in this study.

Age is considered major responsible factor for mortality. Each tree has assumed to be intrinsic mortality rate, only 1% of a cohort could be expected to live long (Age_{max}) to attain their maximum height and maximum diameter (H_{max} and D_{max}). The probability of mortality in relation to maximum age (Age_{max}) is $P_m = 1 - \exp(\frac{-4.605}{AGEMX})$.

Chablis is set in the model in such a way that each tree has probability of mortality of 0.5 to 0.75 in the event of Chablis. In the KIAMBRAM model, the tree is killed in the event of Chablis year if the random number of tree is less than 0.003 (CHPROB). The probability 0.003 indicates that chances of tree fall event 3 times in the period of 1000 year. Local, long residential and aged people were consulted to estimate the above two types of data in this study. However, it was difficult to collect such long durational information, but after triangulation of collected data, CHPROB is fixed 0.001 and probability of mortality is fixed 0.5 to 0.75 for this study.

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The tree whose growth is suppressed due to shading or other factors, their diameter increment is less than 1 mm/year, are subjected to additional probability in the model. The probability of mortality (p_s) due to suppression is fixed to 0.368 (Shugart et al, 1980) in the KIAMBRAM model. This explains that 1% of a suppressed cohort to survive 10 years. Due to lack of sufficient information regarding the suppression mortality in the study area, it is decided to use same probability of mortality (0.368) for suppression threshold in this study also. All the SISPs described in Sections 4.2.3.1, 4.2.3.2 and 4.2.3.3 are present in Table 4.18.

Table 4.18: Re-parameterised site specific parameter

	Sub-routines	**Parameters**	**Value**	**Sources**
1	Growth	Light extinction coefficient (k)	0.37	Matthe and Pilbeam, 2005
		Maximum basal area (SOILQ)	130 m^2/ha	Field consultation (Section 4.2.3.1 (b))
2	Birth	No of requirement per plot (in normal year)	1-20	See Section 4.2.3.2
		In the event of the chablis and the beginning of the simulation when the leaf area index of the plot is less than 1.0.	1-600	
3	Kill	Maximum age		See Section 4.2.3.3
		Mortality increases if diameter increment is less than 0.1 cm/year (suppression mortality)	0.368	
		Chabli : ♦ Occurrence probability (tree fall probability) ♦ Probability of the mortality in the case of chablies	0.001 0.5-0.75	Field consultation

Availability of species in books and articles for sal forest somehow supported to collect some of SPSP but due to lack of long term research in the natural sal forest it was difficult to get most of the species specific parameters. Due to similar climatic zone with the KIAMBRAM model and the study site, most of the SISPs were not changed. Major issue of SISPs was that no more options were provided for changes in the model structure though these parameters are most important for site specific application (Risch et al, 2005). Further researches will contribute to calibrate these foundation parameters for sal forest in Nepal.

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4.3 Model testing

After providing all the values of SPSPs and SISPs (mentioned in Section 4.2) as the inputs for the KIAMBRAM model, the re-parameterization task was completed for this study and model was ready for run to simulate forest dynamics of the study site. The KIAMBRAM model was run to know the value and characteristics of model simulated forest dynamics at five different development stages. Each simulation starts from a bare plot and each result in the yearly average from 100 runs over the given period of time. To test the models reliability, model out puts were compared with stand structure (quantitative) of observed mature forest condition and species composition (qualitative) of similar site's literature.

4.3.1 Quantitative comparison

Simulated model results[6](simulated result of reparameterized the KIAMBRAM model) at year 500 was chosen to make the quantitative comparison between simulated forest and observed matured forest. Two state variable parameters; basal area and stem density were compared. Similarly, stand structure (diameter distribution) and canopy status were also compared. Model simulates only 18 species for this stage which is lower number of species than other earlier development stage and that will be described during the qualitative comparision.

4.3.1.1 Comparison of basal area

Total simulated basal area was 79.28 m^2/ha, which was about three times higher than observed average basal area 26.98 m^2/ha of this study. Observed maximum basal area was 49.56 m^2/ha, this is far less than simulated basal area. This simulated basal area is also higher than western lowland *S. robusta* forest of Nepal (36.0 m^2/ha) of Bardiya National Park (Shrestha and Jha, 1997). Moreover, simulated basal area is also higher than maximum observed basal area of sal forest (61.1 m^2/ha) of Corbett National Park, India (Singh et al, 1995). Above comparision shows that model simulated stand level basal area was much higher than its observed value, therefore not

[6] The term "simulated model result" or "simulated result" or "simulated" in this study denote the outputs of the KIAMBRAM model.

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matched with mature forest condition at field level. So, model is almost failed to simulate the stand level basal area of the mature sal forest. The major reason of showing higher basal area in simulation is due to presence of very larger diameter sized trees in the simulated result than observed forest. Such larger sized trees are not possible to be found in the real situation. In other words, survival of such larger sized tree in the model simulated result is may be due to defect in structure of KILL subroutine set in the model. Species level basal area also was compared. Ten species that having highest basal areas were selected from both sides (simulated and observed data sets) and seven species were common in both groups (their percentage of sharing is compared in Figure 4.7. Basal areas of 11 species were compared giving the priority for seven common species and additional four and they are present in Table 4.19.

Table 4.29: Comparison of basal area between simulated and observed mature forest

SN	Species	Basal area (m^2/ha)		Percentage	
		Simulated	Observed	Simulated	Observed
1	*Shorea robusta*	66.614	21.006	84.02	77.86
2	*Largerstroemia parviflora*	6.300	0.746	7.95	2.77
3	*Adina cordifolia*	4.750	0.114	5.99	0.42
4	*Cleistocalyx operculatus*	0.213	1.967	0.27	7.29
5	*Litsea monopetala*	0.070	0.160	0.09	0.59
6	*Dillenia pentagyna*	0.010	0.737	0.01	2.73
7	*Terminalia bellirica*	0.009	0.346	0.01	1.28
8	*Cedrela toona*	1.040	-	1.31	-
9	*Holarrhena pubescens*	-	0.855	-	3.17
10	*Syzygium cumini*	0.043	-	0.05	-
11	*Terminalia alata*	-	-	-	-
	Total	**79.280**	**26.980**	**100.00**	**100.00**

S. robusta found highest basal area 66.61 m^2/ha in the simulated result. In terms of percentage, this species covers 84% basal area in the simulated stand. Simulated basal area of *S. robusta* was higher than its observed average basal area 21.01 m^2/ha and also higher than observed maximum basal area of *S. robusta* of 44.0 m^2/ha. Therefore, it can be conclude that simulated basal area for *S. robusta* was found much higher than field condition. Comparing the percentages of basal area of *S. robusta* in observation, 77.8% found in this study, where as Timilsina et al (2007) found 79.5% of *S. robusta-Cleistocalyx operculatus* forest in western Nepal. These two empirical studies show that *S. robusta* shares more than 75% basal area in mature sal

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forest. This percentage is matched with percentage of *S. robusta* basal area (84%) in simulated result. However percentage of basal area covered by *S. robusta* almost matched with simulated percentage but due to lack of sufficient empirical data it is difficult to answere 'whether existing mature forest have such higher value of basal area for *S. robusta* or not'?.

Largerstroemia parviflora (6.3 m^2/ha, 8%) was the second highest basal area in the simulated result. But, this species was found fourth highest basal area (0.7 m^2/ha, 2.7%) in the observation. Comparing between simulation and observation shows that observed basal area was quite smaller than simulated result for this species. In observation this species was found well distribution across the plots and reason of lower basal area is due to presences of more smaller sized trees. Khanna (1993) mentioned this species is major associate dominant species for climax sal forest. Simulated basal area is higher than its observed value therefore not matched but percentage was some how satisfactory. It shows that the KIAMBRAM model is not able to predict the basal area of *L. parviflora.*

Adina cordifolia (4.7 m^2/ha, 6.0%) was observed the third highest basal area in the simulated result. In the observation, this species was found only in tenth position and having very smaller basal area (0.11 m^2/ha, 0.4%). Similarly, Timilsina et al (2007) reported smaller ratio (0.7%) in *S. robusta-Cleistocalyx operculatus* forest. It shows that both of basal area values and its percentage in simulation is much higher than its reality. Based on above information it can be mentioned that predicted basal area is much higher than its reality, which was not matched.

Cleistocalyx operculatus shows the fifth highest position of basal area in simulation. The simulated value was very small (0.213m^2/ha, 0.3%) as compared to observed value 1.97 m^2/ha (7.3%). This species was found second highest basal area in observation. Timilsina et al (2007) also found this species has second highest basal area (1.02 m^2/ha, 7.9%) in *S. robusta-B. latifolia* forest. All of the empirical data show that *C. operculatus* is also a major dominat species at the mature sal forest, at the mean time model also simulates within the rank of five but simulated value is slightly lower than the observed data.

Lisea monopetalais is also found dominat species which having basal area 0.7 m^2/ha (0.9%) in model simulated result. Observed basal area was smaller 0.16 m^2/ha

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(0.6%) than simulated and Timilsina et al (2007) did not found this species on their study area in Western Nepal. However, model simulated basal area found slightly higher than observed value but it is much closed with percentage of coverage of basal area.

Dillenia pentagyna is not found as the major species interms of basal area in simulation because simulated basal area is very smaller 0.01 m^2/ha (0.01%). Contradictory, this species found considerable basal area 0.74 m^2/ha (2.7%). Timilsina et al (2007) also reported this species have basal area 6.5% (much higher) in *S. robusta-B. latifolia* forest, 4% in *Terminalia alata-S. robusta* forest and 2% *S. robusta-C. operculatus* forest in western lowland sal forest. Empirical data show this species is also the major species in term of basal area but which was not matched with simulated result because of smaller value of simulated result.

Terminalia bellirica in simulated result was found very smaller basal area (0.009 m^2/ha) and this species occupies only 0.1% of total simulated basal area. But in the observation, this species was found major species and this species occuping basal area 0.348 m^2/ha (1.3%). Timilsina et al (2007) reported that *T. bellirica* occupied 1.0-1.6% basal area in western Nepal also matched with recent empirical data of central Nepal. It is noteable that empirical data of mature sal forest shows *T. bellirica* is an associate species in the mature sal forest simulated basal area for this species is very smaller than its observed data which is not matched.

In the model simulation result, *Cedrela toona* was found having higher basal area (1.04 m^2/ha, 1.3%). Contradictorly, *C. toona* did not found in the mature forest inside the CNP. According to Khanna (1993), this species enters in mid to late successional stage in the moist sal forest. This species did not consist of sufficient basal area in other recent study of mature sal forest data such as; Webb and Sah (2003) and Timilsina et al (2007). Therefore, it can be say that model simulated result for this species is higher than field condition. *C. toona* moderate shade tolerant large size tree.The models has assumption that only shade tolerant higher sized trees can reach at climax stage, which is matched for *C. toona* and this was the major resean of higher basal area in simulatition. It indicates that future adjustment in the model is not only sufficient at the species level investigation; it could be necessity to reconsider on the model assumption in the context of sal forest.

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However, *Holarrhena pubescens* ranked the third highest basal area (0.85 m^2/ha, 3.17%) in the observation but this species was completely absent in the model simulated result. In other words model is not able to predict this species at the climax level. Timilsina et al (2007) reported that *H. pubescens* is presented in the mature sal forest in thier study site but with very smaller basal area. Presence of higher basal area in the study area than western Nepal may be due to sample forest represents the peculiar sal forest types that may not reported yet. It can be conclude that model is not able to perform basal area of *H. pubescens.*

However, *Syzygium cumini* is not observed inside the CNP in the mature forest but this species is abundant in lowland mature sal forest (Timilsina et al, 2007 and Webb and Sah, 2003). Khanna (1993) also mentioned that this species is an important associate species at the lower canopy level in climax sal forest in moist areas. It indicates that *S. cumini* is also climax species in mature sal forest. Model simulated basal area for this species was very low (0.043 m^2/ha) than observed value of western lowland sal forest (0.06-0.40 m^2/ha) reported by Timilsina et al (2007). It can be mention that model is not able to predict basal area of *S. cumini.*

Terminalia alata is the most important and dominat species of mature sal forest but was completely absent in the model simulated result as well as in the observation. This species mixed with *S. robusta* where the soil condition is loamy and relatively lower water table (Troup, 1921). Absent of this species in the model output is significant with current study site because there is absent of such soil characteristics.
Percentage of basal area shared by common dominant species is ploted in Figure 4.8.

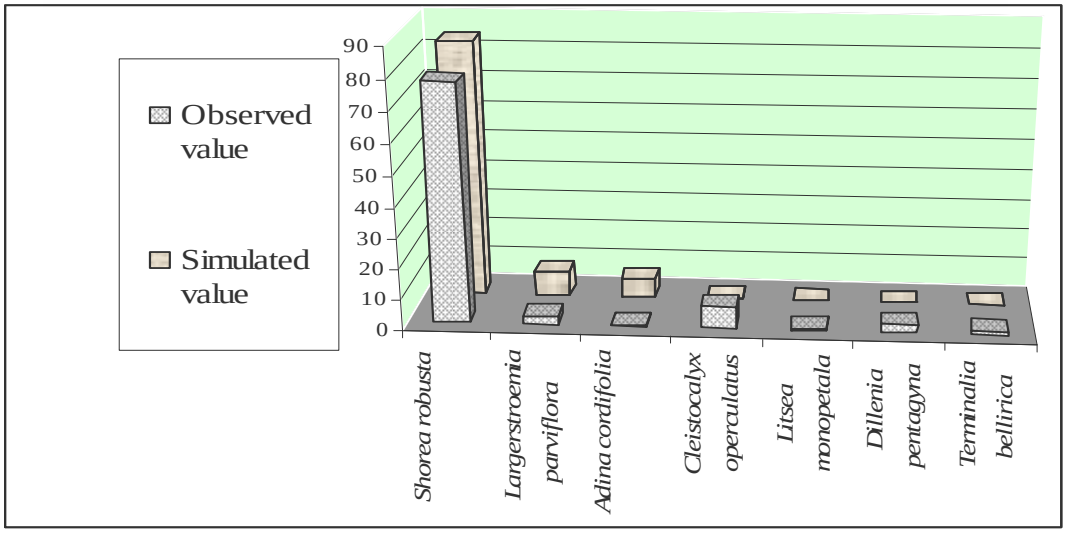

Figure 4.8: Percentage of the basal area of major seven common species

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4.3.1.2 Comparison of Stem density

Total simulated stem density was 960 stem/ha. Average stem density across the 20 pltos was 874 stem/ha from the observation. Maximum observed stem density was 2200 stem/ha. The simulated stem density was also close with 608 tree/ha reported by Webb and Sah (2003) in natural sal forest from Central Nepal. The observed stem density was also not fully satisfactory and it is smaller than usual. In this context, simulated stem density somehow matched with observed stem density at the stand level. For the species level, Table 4.20 shows stem density and percentages between simulated and observed value.

Table 4.20: Stem density comparison between simulation and observation

Species	Stem density (no/ha)		Percentage (%)	
	Observed	Simulated	Observed	Simulated
Shorea robusta	223	60	25.51	6.25
Litsea monopetala	135	60	15.45	6.25
Cleistocalyx operculatus	113	80	12.93	8.33
Dillenia pentagyna	120	60	13.73	6.25
Largerstroemia parviflora	46	60	5.26	6.25
Holarrhena pubescens	50	-	5.72	-
Cedrela toona		160	0.00	16.67
Terminalia bellirica	8	60	0.92	6.25
Adina cordifolia	3	20	0.34	2.08
Mallotus philippensis	37	-	4.23	-
Cassia fistula	2	120	0.23	12.50
Syzygium cumini		20	0.00	2.08
Others	137	260	15.68	27.10
Total	**874**	**960**	**100.00**	**100.00**

S. robusta found having highest stem density 223 stem/ha (25.5%) in the observation. Model simulates 60 stem/ha (about 6%) was quite lower than observed stem density. Stem density from other empirical examples also matched with the recent study but they are also not satisfied with simulated stem density for this species. For example, Timilsina et al (2007) reported average 29% stem were covered by *S. robusta* in western lowland sal forest of Nepal. Similarly, Webb and Sah (2003) found 36.3% stem were belongs to *S. robusta* in natural sal forest of central Nepal. Above observed data shows that matured sal forest in lowland of Nepal consists at least 25-40% stem density. Therefore, it is concluded that simulated stem density for this species is not matched with observed data set and it is lower. In simulation, only 6% trees (lower stem density) shows 84% basal area (higher basal area) which is difficult to match with

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existing field situation. This is due to model simulates only very bigger sized trees for *S. robusta* at mature stages. But some supportive points for simulated results also found. For example, Troup (1921) explained that *S. robusta* is almost even ages forest; therefore having all bigger sized trees at mature stage is matched with this theoretical concept. Troup (1921) also explained that sal forest is almost monoculture but here others species covering 94% (in the context of stem abundant) not matching the simulated value with this concept. In the observation, it is found that most of the trees of this species have either very large sizes or very small sized and very fewer portions of the trees found at middle sized classes which was also not matched with simulated model results. It can be concluded that simulated stem density for *S. robusta* at the mature stage is rather lower than its exsiting condition in the mature sal forest.

Listsea monopetala found fair stem density 60 stem/ha (6%) in simulated model result. But in the observation it found second highest stem density 135 stem/ha (15.45%). Comparing another two recent empirical data of similar area of Nepal, neither Timilsina et al (2007) nor Webb and Sah (2003) noticed this species on their study sites. It can be mentioned that simulated stem density for this species is somehow matched with observed values in terms of stem density.

Cleistocalyx operculatus found fair stem density 80 stem/ha (8.3%) in the simulated result. Stem density in the observation of 113 stem/ha (12.9%) is the fifth highest rank of stem density. Simulated value is slightly lower in percentage but it is not very far from observed value. Timilsina et al (2007) reported average 11.4% stems were occupied by this species in western lowland sal forest. Thus, model is somehow able to predict the stem density of *C. operculatus* in mature lowland sal forest in Nepal.

Dillenia pentagyna also found fair stem density 60 stem/ha (6%) in the simulation. In the observation it was found 120 stem/ha (13.73%). Timilsina et al (2007) reported 7% trees of *D. pentagyna* in *S. robusta-B. latifolia* forest. Webb and Sah (2003) found 2.7% of these species were abundant at the tree level but very nominal ratio at the sampling level. All empirical data show similar percentage of combination of *D. pentagyna* in lowland sal forest of Nepal. Similated value is close with Timilsina et al (2007) but slightly far with CNP's observed data.

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Simulated stem density of *Largerstroemia parviflora* was 60 stem/ha (6%). Observed value was 46 stem/ha (5.3%). In western lowland of Nepal it was observed average 10% and in Central low land sal forest in Nepal recored 7% stem. These empirical data shows that *L. parviflora* is one of the well abundant species in lowland sal forest in Nepal and its stems cover ranges 5-10% of total stem of the stand which is with in the range of simulated figure, it is concluded that the model can predict the stem density of *L. parviflora* at the mature stage.

Hoarrhena pubescens species found the fifth highest rank of stem density in observation. Observed value of stem density of this species was 50 stem/ha (5.72%). Webb and Sah (2003) reported stems of this species were 2.4% in mature natural sal forest of central Nepal. Timilsina et al (2007) found about 1% stems was covered by this species in *S. robusta-B. latifolia* forest. But this species was not found in model simulated result at the mature stage.

A very contradictory stem density is found for *Cedrela toona.* This species has highest stem density in model simulation (160 stem/ha, 16.3%) but this species was not found in the observed mature forest. Timilsina et al (2007) and Webb and Sah (2003) also did not find this species on their sites. This species should not have higher abundant in the mature sal forest. Having unrealistic stem density of *C. toona* indicates that the model is not sufficiently calibrated for the species level composition prediction. The other species were less than 5 percent (60 stem/ha) stem density.

Terminalia bellirica found lower stem density (9 stem/ha, 0.9%) in the observation. Timilsina et al (2007) also found lowest stems of 0.6% on their study area. Webb and Sah (2003) found 2.6% stems. Simulated stem density for this species was 60 stem/ha (6%). Comparing above figures with the model shows higher stems than the observation for *T.bellirica* for mature stage sal forest.

Mallotus philippensis found 37 stem/ha (4.2%) in the observation. Timilsina et al (2007) observed rather lower (1.5%) number of stems in western lowland of Nepal. Webb and Sah (2003) reported 12.9% of stems of *M. philippensis* in their study site is higher than other two sites. However the stem density found variation with places but it is clear that this species is also major composition of mature sal forest. But this species was not found in simulated result at the mature stage.

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Cassia fistula (120 stem/ha, 12.2%) found second highest stem density in the model simulated result, but observation found very lower stem coverage (2 stem/ha, 0.2%) of this species. Webb and Sah (2003) found 0.6% of stems of *C. fistula* from central Nepal's mature sal forest where as Timilsina et al (2007) did not notice any stems of this species. It can be said that model predicts more stems than the observation.

However, simulated stem density is matched with observed stem density but at the species level only few species found good agrrement. Most species were simulated by the model but their number was differing with observed results. Some species were only found in the field observations that were not found in the simulated result. In total, the model is not able to predict the species level stem density.

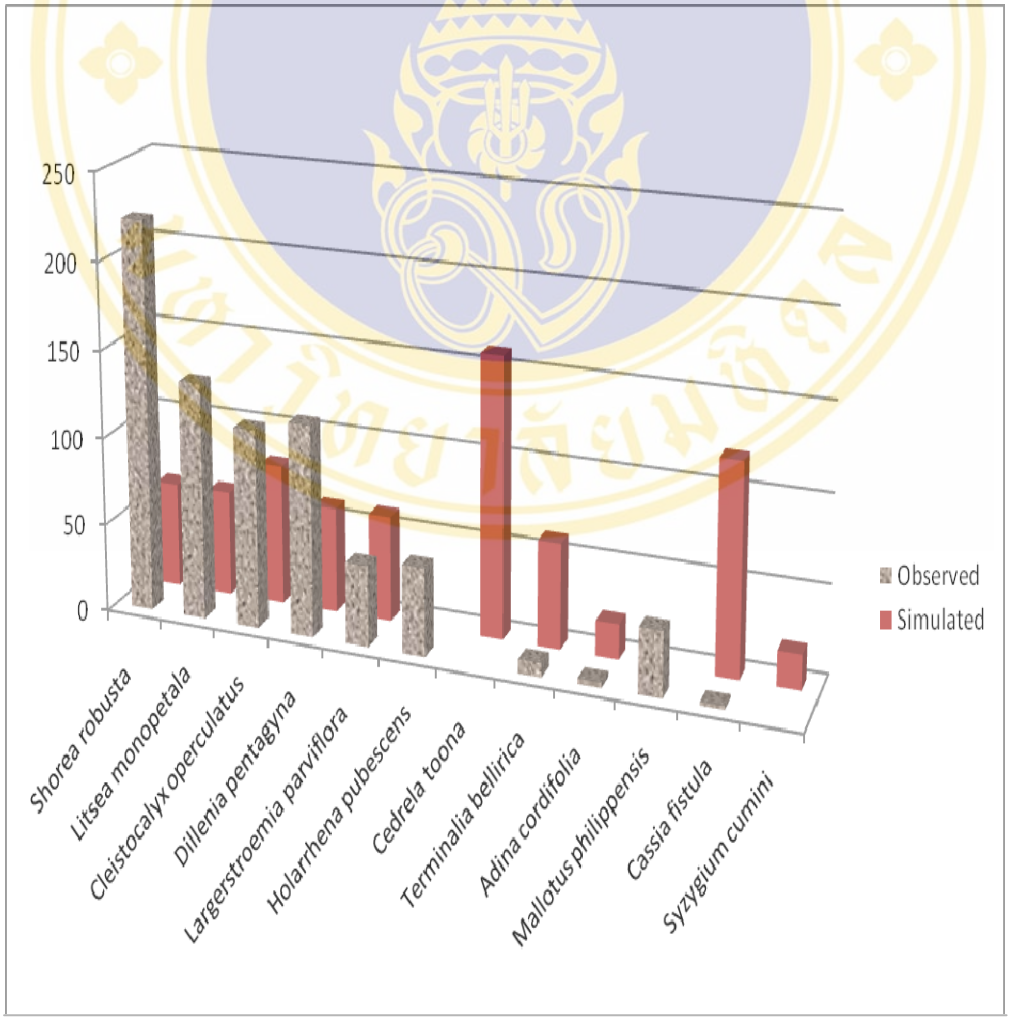

Figure 4.9: Comparison of stem density between simulated and observed value of the mature sal forest

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4.3.1.3 Basal area and stem density comparison at shade tolerant level

Comparisons of number of species, basal area and stem density between observed and simulated results at each shade tolerant level are present in Table 4.21.

Table 4.21: Comparison of observed and simulated result for shade tolerant level

	No of species		Basal area (m^2/ha)		Stem density (no/ha)	
	Observed	Simulated	Observed	Simulated	Observed	Simulated
Shade tolerant	12	4	2.44	1.270	185	320
Intermediate	19	10	2.10	5.085	251	420
Intolerant	11	4	22.44	72.930	438	220
Total	**42**	**18**	**26.98**	**79.285**	**874**	**960**

The model simulates less number of species for each of shade tolarent group than its observed number. Abundant of higher number of species in intermediate tolerant group was common point for both of simulated and observed values. The simulated basal area for shade intolerant group is much higher than observed value and this is due to total basal area in the simulation was higher than observation but the model shows less basal area for shade tolerant species than its observed value. This result is conflicting with the models' assumption for shade intolerant species. Simulated stem density for each shade tolerant group is not matched with observed values; however the total stem density is not much different. The tabular information shows that the model simulated large size shade intolerant species than the observation. Simialrly the model simulated smaller sized trees for shade tolerant than the observation. For the intermediate group, the model shows similar values with the observation.

Percentage of number of species, basal area and stem density to total obtained value for each tolerant level was compared between simulated and observed values (Figure 4.9). Percentage of basal area shows good agreement between two values except the case of shade tolerant level where the simulation shows lower basal area. Similarly, percentage of number of species for each shade tolerant group also shows good agreement between two values. In case of stem density it shows poor agreement in all groups and the big gap found at the intolerant level, where simulated result shows poor stem density.

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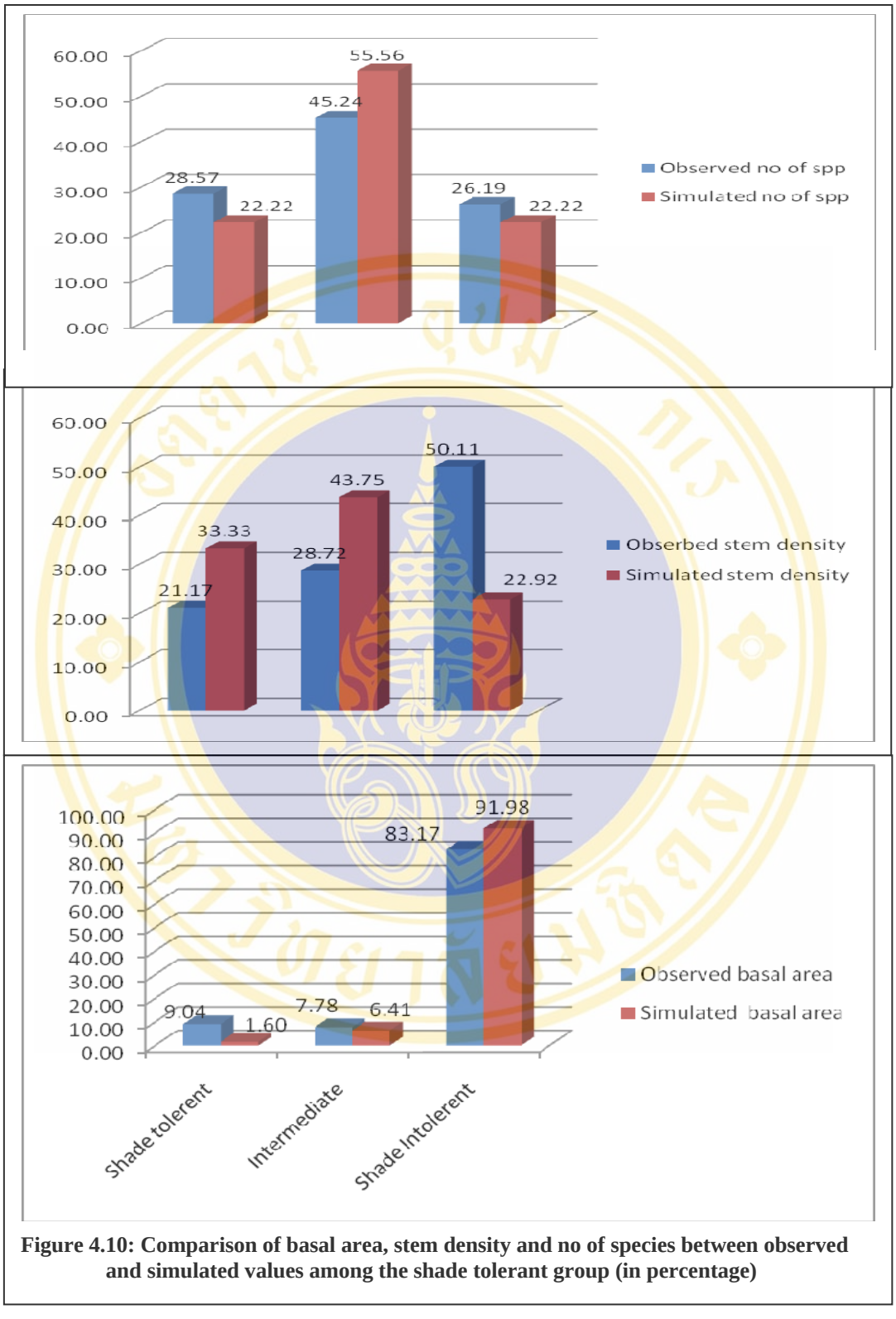

Figure 4.10: Comparison of basal area, stem density and no of species between observed and simulated values among the shade tolerant group (in percentage)

It indicates future investigation should be focused on shade tolerant level to increase the basal area at the mature stage and at the intolerant level to increase the stem density that could help to better prediction.

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4.3.1.4 Comparison of diameter distribution and maximum DBH

The KIAMBRAM model simulates only 5 larger sizes (>50cm DBH) trees per plot (the plot size is 500 m^2). Three trees belong to *S. robusta* with DBH 163.0 cm, 108.6 cm and 63.6 cm, one tree was *L. parviflora* with DBH of 63.0 cm and remaining one tree was *A. cardifolia* with DBH 55.0 cm. Observed larger size trees of similar category were only 2.3 trees per plot, which is lower than the simulated results. It means that the model generated bigger size trees than the observation. At the species level, *S. robusta* found having maximum diameter in the observation. Only three trees of *S. robusta* found >90 cm DBH. Sizes of the maximum observed diameters were 97.5 cm, 91.7 cm and 90.7 cm. Other three species having diameter more than 50 cm were; *H. pubescens* 87.5 cm, *T. bellirica* 52.2 cm and *C. operculatus* 50.9 cm but these three species either absent or having less than 10 cm DBH in the simulated results. Another peculiarity in the simulated result was the absent of middle size trees especially absent of trees having DBH of 20-50 cm. More than 80% trees in the simulated result found less than 5 cm DBH. Indeed, trees of very smaller sizes have higher abundant in the simulated result whereas trees of middle sized class are also present in the observed data.

4.3.1.5 Comparison of height distribution and maximum height

Simulated maximum height was 48.5 m of *S. robusta.* In the observation, maximum height was noticed only 39.0 m of *S. robusta* which is lower than simulated value. The KIAMBRAM model simulates about 80% trees less than 5.0 m height, which is not matched with the observed data set. According to simulated result second vertical layer is dominated by *C. toona* and *C. operculatus* somehow matched. Maximum observed heights of *L. parviflora, C. operculatus, T. bellirica* and *H. pubescens* were more than 20.0 m but the simulation shows very lower heights for these species. The model doid not show middle heights of any tree species which are also not matched with the observed data.

4.3.2 Qualitative comparisons

Due to lack of well documented references of sal forest successional satge and their tentative existence period, it is hard to compare and discuss on the model test.

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The study chose one typical Gangetic alluvium riverine sal succession of Uttar Pradesh India (Khanna, 1993) as an example to make comparative discussion with simulated result. Khanna (1993) described that riverine succession starts from pioneer species of grasses like *Saccharum sontaneum,* then these grasses are replacing by first pioneer tree species. This study is not incorporating the succession of grasses species, therefore simulation stats directly from tree species. To make a clear picture of the sal dynamics and make easy for discussion, simulated model results at years 20, 50, 100, 350 and 500 were used to compare with the forest composition of early successional stage, mid succesional stage, late successional stage, early climax stage and climax stage respectively and they are described in the following sections and all the simulated species are presented in Appendix-L. Species in the Table 4.22-4.26 are placed based on their dominency as higher to lower.

4.3.2.1 Early successional stage

The KIAMBRAM model predicted 30 species (Appendix-L) at this stage. Model predicted dominat species and species from literature are presented in Table 4.22.

Table 4.22: Species at the early successional stage

From simulation	*From literature
Acacia catechu *Dalbergia sissoo* *Largerstroemia parviflora* *Albizia lebbek* *Terminalia bellirica* *Shorea robusta*	*Acacia catechu* *Dalbergia sissoo*

The model simulted result showed that *Acacia catechu* and *Dalbergia sissoo* are most dominant species. Other less dominant species at this stage were *Largerstroemia parviflora, Terminalia beleric, Albizzia leebak,* and *Shorea robusta.* Rest other simulated species were nominally presented in this stage. According to Khanna (1993)*, there are only two dominant species of *A. catechu* and *D. sissoo* in this stage, which is matched with simulated result but he did not mention the composition of rest of the other species at this stage.

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Khanna (1993) mentioned that *L. parviflora* is late successional or early climax species in the riverine succession, but the model simulates this species as a major pioneer species which is not matching. In the model simulated results, *A. leebak*, *T. belerica* and *S. robusta* also observed as pioneer species but *T. belerica* and *S. robusta* species are either mid or late successional species for riverine succession forest (Khanna, 1993). Therefore, simulated result in context of *T. belerica* and *S. robusta* species was not matched. But simulated result for *A. leebak* was not matched with riverine forest succession for this stage but this species was matched with Webb and Sah (2003)'s data set for 20 years secondary successional forest in Central Nepal. Model simulated total number of specie also observed higher in number but without empirical data, it is difficult to make concrete decision. It can be concluded that the KIAMBRAM model is able to closely simulate the survive composition of the early succesional pioneer species with exceptional of some extra species. It can be concluded that the KIAMBRAM model is able to closely simulate the survive composition of the early succesional pioneer species with exception of some extra species.

4.3.2.2 Mid-successional stage

The KIAMBRAM model simulated 33 species at this stage (Appendix-L). The model simulated dominant species and species from reference are compared in Table 4.23.

Table 4.23: Species at the mid- successional stage

From simulation	From literature
Acacia catechu *Cedrela toona* *Dalbergia sissoo* *Terminalia bellirica* *Litsea monopetala* *Shorea robusta* *Adina cordifolia* *Cleistocalyx operculatus*	*Acacia catechu* *Dalbergia sissoo* *Holoptelia spp.* *Adina cordifolia* *Albizzia procera*

Model is able to predict three species among the five species of references. Model is not able to predict *Holoptelia spp.* and *Albizzia procera* because these two species are not occured in the current study site and hence they were not included in

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the species list of model input. Comparing above simulated result with available references, following conclusion were drawn for this stage. (1) Higher abundance and dominant role of *A. catechu* and *D. sissoo* were matched with Khanna (1993). (2) Simulated new species (were not presented in earlier simulation) *M. philippensis, Pterocarpus marsupium, S.cumini* and *C. toona* (see long list of species in Appendix L) were not matched because these species were observed at late succession stage and climax stage species in United Province of India (Troup, 1921), and Khanna (1993) also mentioned all these species are late successional species. (3) It is difficult to comment to the rest other simulated species composition for this stage due to lack of sufficient references. Comparision of the result concludes that model is able to predict species composition at mid-successional stage for lowland sal forest.

4.3.2.3 Late-successional stage

The KIAMBRAM model simulated 23 species at this stage (Appendix-L). Major dominat species from the model simulation and literature are presented in Table 4.24.

Table 4.24: Species at the late- successional stage

From simulation	From literature
Shorea robusta *Dalbergia latifolia* *Cedrela toona* *Cleistocalyx operculatus* *Terminalia bellirica* *Adina cordifolia* *Bombax ceiba* *Largerstroemia parviflora* *Litsea monopetala*	*Holoptelia species* *Adina cordifolia* *Lagerstroemia parviflora* *Bombax ceiba Terminalia belerica* *Trewia nudiflora* and *Cedrela toona*

In simulation, *S. robusta* was found most dominant and followed by *Dalbergia latifolia, Adina cordifolia* and *Cedrela toona*. Similarly, *Litsea monopetala* and *Cleistocalyx operculatus* were less abundant in the simulation. All the model simulated species were matched with riverine sal forest succession of late-successional stage (Table 4.24) except *Trewia nudiflora*. Due to lack of sufficient empirical data about the species composition for this stage, it is difficult to make comment about rest of simulated species composition whether they should present at this stage or not.

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After comparing above simulated results with species composition of riverine sal forest succession at late-successional stage from Table 2.3 (Khanna, 1993), following conclusions were made. (1) Absent of *A. catechu* and *D. sissoo* species in the simulation is matched with similar stage of riverine sal forest succession (Khanna, 1993). (2) Dominancy of *S. robusta* in simulation at this stage is not matched, because of major three species i.e. *Adina, lagerstroemia* and *Terminalias* should show dominancy than *S. robusta* at this stage (Khanna, 1993). (3) Due to lack of sufficient empirical data about the species composition for this stage, it is difficult to make comment about simulated species composition whether they should present at this stage or not. It can be conclude that the KIAMBRAM model is able to predict species composition at late sucesional stage.

4.3.2.4 Early climax stage

Simulation year 350 was chosen to compare with reference for early climax stage. The KIAMBRAM model simulated 26 species at this stage (Appendix-L). Major dominat species from the model simulation and literature are presented in Table 4.25.

Table 4.25: Species at the late- successional stage

From simulation	From literature
Shorea robusta *Terminalia alata* *Dalbergia latifolia* *Adina cordifolia* *Cedrela toona* *Bombax ceiba* *Largerstroemia parviflora* *Terminalia bellirica* *Cassia fistula* *Desmodium oojeinense* *Litsea monopetala* *Cleistocalyx operculatus*	*Adina cordifolia* *Lagerstroemia parviflora* *Bombax ceiba* *Terminalias* *Shorea robusta*

In simulation, *S. robusta* was found most dominant which was followed by *T. alata, D. latifolia, A. cordifolia* and *C. toona*. Similarly, *Litsea monopetala* and *C. operculatus* were less abundant in the simulation. All the model simulated species were matched with riverine sal forest succession of late-successional stage (Table 4.25). Due to lack of sufficient empirical data about the species composition for this

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stage, it is difficult to make comment about rest of simulated species composition whether they should present at this stage or not.

After comparision of above prescribed model simulated data with riverine sal forest succession at early climax stage from Table 2.3 (Khanna, 1993), following conclusions were made. (1) Dominaitng role of *S. robusta* in simulated result is somehow matching with similar stage of riverine sal forest succession (Khanna, 1993). (2) *T. alata, L. parviflora* and *A. cordifolia* abounds at co-dominant in model simulated result were some how matched. It can be further concluded that species composition in both cases are almost similar but their dominacy and aboundent were different. It can be concluded that the KIAMBRAM model is able to predict species composition at late sucesional stage.

4.3.2.5 Climax stage

Model simulated result at Year 500 was considered the species composition at mature stage sal forest. To know the model's performance at the mature stage, simulated species were compared with observed mature forest species and they are presented in Table 4.26.

Table 4.26: Species at the climax stage

From simulation	From observation
Shorea robusta *Largerstroemia parviflora* *Adina cordifolia* *Cedrela toona* *Cleistocalyx operculatus* *Cassia fistula* *Litsea monopetala* *Syzygium cumini* *Dillenia pentagyna* *Terminalia bellirica* *Butea monosperma* *Grewia optiva* *Bauhinia variegata* *Aegle marmelos* *Myrsine semiserrata* *Diospyros malabarica* *Cassine glauca* *Buchanania latifolia*	*Shorea robusta* *Cleistocalyx operculatus* *Largerstroemia parviflora* *Dillenia pentagyna* *Terminalia bellirica* *Litsea monopetala* *Adina cordifolia* *Diospyros malabarica* *Grewia optiva* *Buchanania latifolia* *Syzygium cumini* *Myrsine semiserrata* *Butea monosperma* *Cassia fistula* *Cassine glauca*

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The KIAMBRAM model shows only 18 species in the simulation for the mature forest. In the simulation, *S. robusta* was found highly dominated species. Most of the individuals of *S. robusta* was found over 200 Year old in the simulated result. At the co-dominant level: *L.parviflora, A. cordifolia, C. operculatus* and *C. toona* were present in the simulation. Similarly, simulation result shows: *L. monopetala*, *C. fistula, D. pentagyna* and *T. bellirica* in the lower canopy layer. Rest other species were found having nominal frequency and smaller sized in the simulation result. Model simulated three species: *Cedrela toona, Bauhinia variegata* and *Aegle marmelos* were not found in observation. After comparing these simulated species with observed forest, following points were concluded: (i) dominancy of *S. robusta* in the simulation matched exactly with observed forest condition, (ii) forest is near to even aged as shown by simulation is matching with characteristics of mature *S. robusta* forest described by Troup (1921), Jackson (1993), Tiwari (1995), Nagendra (2002), Pandey and Shukla (2003), Rautiainen (1999), Rautiainen et al (2000), Gautam and Devoe (2006), and (iii) presences of *Adia, Lagerstroemia, Terminalias* and *S. cumini* at the lower canopy level in the model simulated result are exactly matching with major species composition of mature *S. robusta* forest explained by Khanna (1993) and Jackson (1994). Evaluations of above three concluding points indicate that species composition of the KIAMBRAM model's simulated result and observed forest was similar. Thus, model is able to predict the species composition for climax stage sal forest.

4.3.3 Remarks on model test

Sal species were observed from very beginning (pioneer stage) to all stages of succession and finally reaches at climax stage as the most dominant species specially in model simulated result and also in observed forest (Appendices C-D, and Webb and Sah, 2003). On the other hand, sal is shade intolerant and moderatly growing species, as an ecological principle this should not go longer age as it starts from pioneer level. Therefore, it found conflicting with the KIAMBRAM model's assumption because this forest is tropical based species. Most of the gap model developed for the temperate forest assumed that shade tolerant species only reach as a dominant tree in climax

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forest (Botkin et al, 1972; Botkin, 1993; Huth and Ditzer, 2000; Liu and Ashton, 1995; Seagle and Liang 2001; Shugart et al, 1980; Shugart, 1984). However, the study could not achieve good agreement between simulation and field conditions due to many limitations but simulated results in this study for sal forest indicate that gap models have significant potentiality to study the succession of sal forest dynamics. Highly differences of species level stem density between simulation and observation is similar as found by Roachanakanan (2002) in Australian subtropical rain forest. It shows there is necessity for improvement in model structure especially for stem density prediction. The reasons of differences between two results are many and they will recommend in the next chapter for improvement of model's applicability.

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CHAPTER 5
CONCLUSION AND RECOMMENDATIONS

This chapter aims to summarize the findings of the study, to build up conclusions and formulate recommendations that can contribute accordingly to the informed managerial and policy making level, academic field and further studies. This chapter will discuss the limitations of the study and further applicability of the study as well.

5.1 Conclusion

Conclusions are drawn based on the summary of major findings in the sequential order of study's objectives, (i) floristic structure and composition of the mature sal forest, (ii) re-parameterize the KIAMBRAM model with reference to sal forest and (iii) test of the KIAMBRAM model to predict the sal forest.

5.1.1 Floristic structure and composition of the existing mature sal forest in lowland of Nepal

The average basal area of 26.98 m^2/ha found in the mature sal forest concludes that observed mature forest was medium to poor stock. Absent of very large sized trees and less abundant of middle sized trees were the major reasons of low basal area. Selective cutting of large trees before the time of declaration of National Park and production capacity of the study site may be causes of absence of very large sized trees. *Shorea robusta* is found the most dominant species covering more than 75% of the basal area. Only two species, i.e., *S. robusta* and *Cleistocalyx operculatus* consist of more than 1 m^2/ha basal area.

Average stem density of trees having DBH >1.27 cm was 874 stem/ha implies that forest is poorly stem composition. Poor stem density may be due to lack of

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availability of sufficient stems in all the diameter classes and more influence by poor stem at sapling stage. Having lower density may be due to several reasons, such as: effect of the fire, dominancy of grass and allowable for grass collection, abundancy of weeds and climbers, and lack of sufficient light at the lower canopy level that is required for the growth of the sal forest (Rautiainen and Suoheimo, 1997). *S. robusta* had dominant stem density which comprises of more than 25% stem/ha. Only four species; *S. robusta*, *Largerstroemia monopetala*, *Dillenia pentagyna* and *Cleistocalyx operculatus* were dominant in the context of the stem density where each species shares more than 10% stem/ha in the stand. Dominancy of *S. robusta* and less abundancy of other species are due that sal forest is not rich in other associate species (Stainton, 1972), *S. robusta* exists mostly pure and even aged stand in the sal forest (Troup, 1921) and *S. robusta* is considered climax species in the sal forest (Champion and Seth, 1968).

In the context of diameter distribution, only 5% of the trees were found at the larger sizes (>50 cm DBH) in the stand. Only 1% of the trees were found more than 80 cm DBH and no trees were found more than 100 cm DBH. About 50% of the trees were very small in size (DBH<5cm). Therefore, it can be concluded that most of the stems were of young age which implies that forest at the lower canopy was not very old. Diameter distribution at species level shows that *S. robusta* was present at all the diameter classes and its abundancy was higher in the upper diameter classes. Only four species; *S. robusta*, *C. operculatus, Holarrhena pubescens* and *Terminalia bellirica* were found more than 50 cm DBH and 10 species were noticed having more than 30 cm DBH. Maximum observed diameter of 94 cm belongs to *S. robusta.*

Average height of the top canopy layer was 28.7 m. Top canopy layer was completely dominated by *S. robusta.* About 80% of the selected tallest trees belong to *S. robusta* and its maximum observed height was 40 m. At the sub canopy layer, *S. robusta* was found dominant and *Cleistocalyx operculatus, Terminalia bellirica* and *Largerstroemia Parviflora* were also found very rarely with dominant height in this stage. At the lower canopy layer, *Litsea monopetala* and *Dillenia pentagyna* were the dominant species. The ground layer was mostly coverd by grasses and this caused most tree species poorly regenerated.

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S. robusta was recorded in all the 20 sample plots. Therefore it can be concluded that this species was well and evenly distributed. *D. pentagyna* and *C. operculatus* were found in more than 80% of the sample plots, and another three species: *L. monopetala, L. parviflora* and *H. pubescens* were found in more than 60% of the sample plots. Therefore it is concluded that these six species were the common species in the sal forest of the study area.

Based on the findings, following conclusions were illustrated:

- Mature sal forest has poor stem density and poor to moderate basal area.
- Large sized trees were rare in the mature sal forest.
- Basal area, stem density and top canopy layer in the mature sal forest were dominated by *S. robusta.*
- *S. robusta* was present in all sized classes and comparatively highly abundant in the upper diameter classes.
- *S. robusta* and other five species: *Dillenia pentagyna, Cleistocalyx operculatus, Largerstroemia parviflora, Litsea monopetala* and *Holarrhena pubescens* were found well and evenly distributed in the study area.
- Abundant of grasses is high where the site was relatively lower altitude, higher water stress and open canopy.
- The sal forest in the well drained area and elevated plain area was dense, mature and well stock condition than grassy area.
- Major disturbance factor of sal forest in the study area was forest fire and frequency of the fire was on annual basis.

5.1.2 Re-parameterization of the model

Altogether 55 tree species were found under different management regime in the study area of lowland sal forest of Nepal and they were reparameterized and then used as a new list for model simulation. The number of species is comparatively long in the context of species poor sal forest but smaller when compared with the KIAMBRAM model which includes 125 species.

Species specific parameters (SPSPs) for all the 55 species were collected, processed and valued with different sources. Most of the SPSPs included D_{max}, H_{max},

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shade tolerant, seed phenology, seed longevity, types of seed dispersal agents, and types of soil required for plant establishment were collected from reviewed literature and partly through consultation with experts and experienced persons. The two SPSPs i.e. ∂D_{max} and Age_{max} were not found in any of literature, therefore they were re-parameterized through preparation of growth table of individual tree species. Growth factor (G) was not available in the literature as well and it was computed by mathematical formula using other re-parameterized values.

In the context of the site specific parameters (SISPs), only three site specific parameters: light extinction coefficient (k), maximum basal area (SOILQ), and probability of tree fall were re-parameterized through literature and consultation, and rest of the other parameters and assumption of the KIAMBRAM model remained unchanged.

Re-parameterized values in the KIAMBRAM model for many species may not be matched with the same species of the study area, because most of these values were collected from available literature of diversified geological location due to lack of literature available related to the study area. Another reasons of not matching may be due to most of the parameters were estimationed/ placed through different methods/ sources, that should be come from past long term research findings. Collecting the information from literature is more reliable than estimation by different means. Therefore, there are many rooms for its further improvement of these parameters.

5.1.3 Testing of the KIAMBRAM model

Model simulations of 500 years were used to assess the mature forest. Quantitative comparisions of the mature sal forest were carried by comparing the basal area, stem density and canopy height. Comparison of basal area between simulation and observation for the mature sal forest of lowland of Nepal shows that model cannot perform the basal area at the stand level, because simulated value was found much higher than the observed values (not within the range of 10-20% error). At the species level, *S. robusta* was found with highest basal area in both of simulation and observation. Percentage of basal area shared by *S. robusta* in both cases: simulation and observation was found similar values. Comparision of species having higher

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percentage of basal area in simulation and observation showed that most of the species were common. In summary, it can be concluded that the KIAMBRAM model is not able to predict basal area at the stand level whereas at the species level it makes moderate agreement.

Comparison of stem density between simulation and observation concludes that the KIAMBRAM model is able to predict stem density at the stand level for lowland sal forest in Nepal. At the species level, neither their values nor their percentage were matched. Therefore, it can be concluded that there is poor[1] performance of the model for species level's stem density simulation. At the diameter distribution level, simulated trees were found very large DBH than observation, very fewer trees of middle size than observation and very higher density (>80% trees) was found in lower diameter (<5.0 cm DBH) than observation. Diameter distribution was also not matched between simulation and observation; therefore, it shows the KIAMBRAM model is not able to predict the diameter distribution for the mature sal forest. At the canopy layer, simulated trees were found higher in height than in observation, very few number of trees were found in the middle height layer than observation, and very large number of trees were found at the lower height (>80% trees were found having less than 5 m height) than observation, which was also not matched. Thus, the KIAMBRAM model is not able to simulate the canopy height of the mature sal forest.

Qualitative comparision of the mature sal forest were carried out through comparing the species composition at different successional stage between simulated species and species from literature. Species composition of the simulated result at the early and mid-successional stage shows that three species: *Acacia catechu, Dalbergia sisoo* and *Lagerstroemia parviflora* are the first pioneer species and leading in the stand. *A. catechu* and *D. sissoo* were earlier established than *L. parviflora* in the simulation which is matched with literature (Khanna, 1993). At the late-successional stage, model simulation shows that *S. robusta*, *Dalbergia latifolia* and *Terminalia alata* were the dominant species which was also matched with the literature. At the climax stage, model simulation shows that *S. robusta* was most dominant species in the stand, which was matched with species composition of observed forest in the study. Moreover, most of the other species composition at the climax stage was matched

[1]Poor performance: Difference of simulated value and observed value far from the range of 10 to 20 %.

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between simulation and observation. Therefore, it is concluded that model's prediction of species composition for different successional stage matched with riverine succession of sal forest. Thus, it can be concluded that the KIAMBRAM model is able to predict the species composition at different successional stage of sal forest dynamics.

5.1.4 Overall conclusion of KIAMBRAM model

The KIAMBRAM model developed site and correct study site were matched with similar climatic zone, therefore this model was chosen to apply for sal forest dynamics. Another reason for choosing the KIAMBRAM model was that this model has considered more components than other gap models like: CHABLI, STRGLE, and LUMBER. Some assumptions of the KIAMBRAM model are not matched with sal forest situation but these assumptions have minimal impact. For example, one of the assumptions in the KIAMBRAM model is that only shade tolarent species will dominate at the climax stage forest but this assumption is not matched with sal forest because in sal forest, shade intolarent species dominated in the climax stage. Based on adopted methodologies for the model reparameterization and model result tested, following conclusions are made for the KIAMBRAM model in the context of the sal forest.

- Due to lack of past long-term reasearch data, re-parameterisation of the gap model is rather difficult. Data of long term permanent plot is essential for reparameterization.
- Inclusion of species specific characteristics in the model is an opportunity to study the insight of the sal forest species dynamics.
- SISPs reparameterization is rather difficult than SPSPs and needs to change the model structure as per the site situation.
- The KIAMBRAM model has potential to study the successional dynamics of the sal forest because this model is able to simulate the dominant species with the references in all the stage of the succession.
- The KIAMBRAM model can not predict the stand level basal area. It also can not predict basal area and stem density at the species level. Therefore,

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there is a need to recalibration of the parameters for quantitative prediction of the sal forest dynamics.

- Major defect in the model for quantitative prediction is due to lack of proper consideration to the KILL and BIRTH subroutines for sal forest.

5.2 Limitation of the study

Following limitations were faced to complete this study.

5.2.1 Availability of literature, previous study and expert

- Application of forest gap modeling is being the first kinds of the study for the sal forest; there was very little access of information about the parameters of D_{max}, H_{max}, shade tolerant, seed dispersal, seed phenology and seed longevity and if so, it was not collective forms. There was completely lack of information for ∂D_{max} and Age_{max} of SPSPs and for all the parameters of SISPs.
- However, the study was expected to collect the information through consultation with the experts for those parameters which were not available in any references. But, this aim was not fully satisfied because most of the consulted experts were found not having experience in the species specific issues.
- Neither there was any growth table developed in the natural condition nor any research data set to study the vegetation inside the protected area system.

5.2.2 Method of re-parameterization

- Applying similar assumption and formula for all the species for the preparation of growth table was not matched with growth data and growth table was not precisely developed. Other alternative methodology should be applied.

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5.2.3 Method of empirical data collection

- Though sal forest is not homogeneous (Timilsina et al, 2007) but in this study, empirical data were collected from one locality and limited number of the samples, which may not be sufficiently representative for the lowland mature sal forest of Nepal.
- Only mature stage sal forest was intensified in field work for the measurement in this study. However, few sample plots were employed in early successional stage and are in community managed forest but they were also not used for comparison because their origin was secondary succession. Beside this, other different successional' sal forest was not able to incorporate in the field work due to lack of time and resources available for the study.
- Data collection method should intensify the discussion in each sample plot with experts and local residents to know the ecological process, SPSPs and SISPs. Provided time did not permit to intensify. This study experienced the limitation of time for data collection and field work.

5.2.4 Reliance on model structure and assumption

- The model does not have the option to change few of the site specific values, for example: probality of recuitment, mortality rate.
- The model does not have options for modifying the model assumptions.
- Determination of site specific parameters was rather difficulties; therefore most of them used the same value as the KIAMBRAM model.

5.2.5 Site characteristics were not incorporated by the model

- However major disturbance factor of the sal forest in lowland of Nepal was noticed as forest fire, but this phenomenon/ component is not included in the model structure

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- Sal trees grow only in specific soil condition, to reach the climax level soil also should reach climax level called edaphically climax (Toumey, 1946). This part is not included in the model structure.
- However the objective of the study is not related to grass vegetation and the KIAMBRAM model is for tree species dynamics but nature of sal forest is: gap area at first covered by grass and larger grassland patches is common in sal forest. But the model only covers the tree species and does not incorporate these characteristics.

5.3 Recommendation

5.3.1 Recommendation for the further study

- Lack of sufficient field data makes confusion and hard to confidently reach at conclusion. Knowing detailed floristic structure and composition dynamics at the field is rather important. Therefore, further investigation is necessary through gathering the sample data from different parts of lowland of Nepal's sal forest to explore and document the type and condition of the existing mature sal forest of lowland of Nepal. Similarly, more data should be collected from different successional stages of the lowland sal forest that would be helpful to compare with the simulated data that contribute to the calibration of the model.
- Lack of some important information of the sal forest such as: how much maximum basal area can be held by per unit ha of the sal forest, consequences of species composition and structure, and favorable ecological condition for such environment. Further research is necessary to access such types of grounded information.
- Collected SPSP values may not be accurate at every context because parameterization was initiated first time and without having sufficient relative literature. Only the further research can contribute to modify SPSP values to make more appropriate for Nepal's lowland sal context. More intensify work should be focused on modification of ∂D_{max} and $Age_{max.}$

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- Computation of G, ∂D_{max} and Age_{max} found interconnected which have major influence on model. If Age_{max} can compute separately from the above part, it could be more useful for independent prediction. Further investigation is necessary to solve this complicated issue.
- This model structure consists of only three types of seed dispersal agents: bird, wind and gravity and it is not incorporating other seed dispersal agents of the sal forest species like: large mammal, water, and water and gravity. Further research could support their inclusion in the model structure.
- Major disturbance factor for the regeneration development in the study area found forest fire but this component does not exist in the model. Further investigation will contribute its impact on sal development.
- Soil factor is most important for development of the sal forest. The KIAMBRAM model has not incorporated the dynamic changes of the soil condition that is favorable for the particular species. For example, alluvial deposited river belt soil at the initial condition gradually converted to high porosity deep water tabled well drainage soil with respect to *Acacia* and *Dalbergia* species in pioneer stage to *Shorea*, *Terminalies* in the climax stage. These types of dynamic change in soil are not found in model structure. Therefore further research should incorporate these phenomena as major component in model structure.
- Developments of the grassland in the gap area and dominancy of the grasses at the ground cover were observed in the study area. Troup (1921) also argued that the sal forest is connected with grassland but this phenomenon is lacking in the model assumption and structure. Further investigation is necessary for inclusion of this component in the model and impact of the grasses on growth of the tree species. Moreover it is also found that Park administration also provided the authority to collect the grass from these sites for the local people once a year. This might have effect on development of the sal forest. Therefore another research issue could be dynamics of sal forest under defined grass cutting scenarios.
- The KIAMBRAM model assumes only shade tolerant species reaches at the climax stages and shade intolerant species lives pioneer to mid succession

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stage, but in the sal forest situation found different. *S. robusta* which is a shade intolerant species, it is found at the climax stage as a main dominant species. Similarly other associate species of the sal forest at the climax stage was also found belonging to intermediate and shade intolerant species. Model assumption for this forest should also be changed based on the above phenomena. Further research may be useful to know reason of the sal species reaching at the climax stages.

- In this model, same mortality threshold rate was applied for all sized trees, therefore further investigation is suggested impact on simulation using different mortality thresholds for different sized trees.
- Present study is only limited in the protected forest. Further investigation is necessary to know the application of the model in different thinning and logging scenarios for sal forest in lowland of Nepal.

5.3.2 Recommendation for policy level implication

- Government should allocate the budget and resources for research and extension work with collaboration of academic institutions. Priority should be given for ecological research.
- Government should develop and implement the mechanism of permanent research plot establishment inside the core area of the National Park with regular ecological monitoring mechanism.
- Government should develop the mechanism for documentation of the research and their implication should be developed and implemented in the forestry and environmental sectors.

5.4 Further application of the study

This study is application of the long term characteristic study of sal forest dynamics under different management scenarios through playing in computer within very short time that is almost impossible to study in the real situation. Therefore, product of this study and further modification can direct the guideline for vegetation

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conservation action and finally it can contribute for long term conservation and sustainable livelihood in Nepal and in regional level as well.

5.5 Final comments

Though this study focused only the species specific parameterization and not able to modify the other structures in the context of the sal forest, simulation result shows that application of individual based gap model have potentiality to study the sal forest stand dynamics. This study has made the foundation of computer simulation individual based gap model to study the dynamics of the sal forest in the context of lowland forest of Nepal. Now onwards it has opened the door to discuss, comment, make awareness and further research on gap dynamics of the sal forest. This study further expects that the Government will also emphasis in this field of ecological research and extension work, and new young researchers will approach in this ground and their modification and improvement of the model will competent to predict the sal forest dynamics to contribute the long term conservation and sustainable livelihood.

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REFERENCES

Alam, M. K. (1996). Diversity in the woodly flora of sal (*Shorea robusta*) forest of Bangladesh, Bangladesh, *Journal of Forest Science* 24: 41-51.

Behera, S. K. and Misra, M. K. (2006). Above ground tree biomass in a recovering tropical sal (*Shorea robusta* Gaertn. f.) forest of Eastern Ghats, India, *Biomass and Bioenergy* 30: 509-521.

Botkin, D. B. (1981). Causality and succession, Forest succession: concepts and application. West, D. C., Shugart, H. H. and Botkin, D. B. New York, *Springer-Verlag***:** 36-55.

Botkin, D. B. (1993). Forest Dynamics, An ecological model, Oxford University Press New York, pp 309.

Botkin, D. B., Janak, J. F. and Wallis, J. R. (1972). Some ecological consequences of a computer model of forest growth, *Journal of Ecology* 60: 849-872.

Bugmann, H. K. M, Yan, X, Sykes, M. T., Martin, P., Lindner, M., Desanker, P. V.and Cumming, S. G. (1996), A comparison of forest gap models: model structure and behaviour, *Climate Change* 34(2): 289-313.

Busing, R. T. and Clebsch, E. E. C. (1987). Application of a spruce-fir forest canopy gap model, *Forest Ecology and Management* 20: 151–169.

Champion, H. and Osmaston, F. C. (1962). E. P. Stebbing's The forests of India, Volume IV, Oxford University Press, London.

Champion, H. G. and Seth, S. K. (1968). General silviculture for India, Government of India, Delhi.

Daalen van, J. C. and Shugart, H. H. (1989). OUTENIQUA-a computer model to simulate succession in the mixed evergreen forests of the southern Cape, South Africa, *Landscape Ecology* 2(4): 255-267.

DeAngelis, D. L. and Waterhouse, J. C. (1987). Equilibrium and nonequilibrium concepts in ecological models, *Ecological Monographs* 57(1): 1-21.

DFRS (1999). Forest resources of Nepal (1987-1998). Kathmandu, HMGN, Department of Forest Research and Survey.

Copyright by Mahidol University

Dinerstein, E. (1979). An ecological survey of the Royal Karnali–Bardia Wildlife Reserve, Nepal. Part I. Vegetation, modifying factors, and successional relationships, *Biological Conservation* 15: 127–150.

DoF. (2004). Community forestry resource inventory guideline, Department of forest, Community Forest Division, Babarmahal, Kathmandu, Nepal.

DoF. (2005). Forest covers change analysis of the Terai districts (1990/91-2000/01), Department of Forest, Babarmahal, Kathmandu, Nepal.

DoF. (2007). Community forestry national database, Community Forest Division, Department of Forest, Babarmahal, Kathmandu, Nepal.

Doyle, T. W. (1982). FORICO: Gap dynamics model of the lower montane rain forest in Puerto Rico, Oak Ridge National Laboratory, Environmental Sciences Division.

Gautam, K. H. and 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 Advance Access*, DOI 10.1093/forestry/cpi063, Forestry 79: 81-101.

Global Environment Outlook (2003). 'Global Environment Outlook' year book-3, Synthesis, United Nations Environment Program.

Grimm, V., Wyszomirski, T., Aikman, D., Uchmanski, J. (1999). Individual-based modelling and ecological theory: synthesis of a workshop, *Ecological Modelling*, 115: 275-282.

HMGN (1968). Soil survey of Chitawan Division. Forest Resources Survey Publication No. 5, His Majesty's Government of Nepal.

HMGN (1988). Master plan for forestry sector of Nepal, Ministry of Forest and Soil Conservation, His Majesty's Government of Nepal.

HMGN (2001). State of environment of Nepal, Kathmandu, HMGN, Ministry of Environment and Population.

HMGN (2004). Terai arc landscape-Nepal: Strategic plan 2004-2014, Ministry of Forest and Soil Conservation, Kathmandu, Nepal.

Holbrook, N. M. and Lund, C. P. (1995). Photosynthesis in forest canopies, In: Lowman, M. D. and Nadkarni, N. M. (eds). Forest canopies, Academic Press, California: 430-441.

Copyright by Mahidol University

Holling, C. S. (1964). The analysis of complex population processes, *Canadian Entomo* l 96: 335–347.

Huston, M., DeAngelis, D. L., Post, W. M. (1988). New computer models unify ecological theory, *BioScience* 38: 682–691.

Huth, A. and Ditzer, T. (2000). Simulation of the growth of a lowland Dipterocarp rain forest with FORMIX3, *Ecological Modelling* 134(1): 1-25.

Huth, A., Drechsler, M. and Kohler, P. (2004). Multicriteria evaluation of simulated logging scenarios in a tropical rain forest, *Journal of Environmental Management* 71(4): 321-333.

Jackson, J. (1994). Manual of afforestation in Nepal, Ministry of Forest and Soil Conservation, Forest Research Center, Babarmahal, Kathmandu, Nepal.

Kandel, K. R. and Shrestha, K. (2001). Tropical secondary forest in Nepal and their importance to local people, *Journal of Tropical Forest Science* 13(4): 691-704.

Kellomaki, S. and Vaisanen, H. (1991). Application of a gap model for the simulation of forest ground vegetation in boreal conditions, *Forest Ecology and Management* 42**:** 35–47.

Khanna, L. S. (1993). Principle and practice of silviculture, fifth edition, Khanna Badhu, Dehradun, India.

Kira, T. (1978). Community architecture and organic matter dynamics in tropical lowland rain forests of Southeast Asia with special reference to Pasoh Forest, West Malaysia. Tropical trees as living systems. Tomlinson, P. B. and Zimmermann, M. H. New York, Cambridge University Press**:** 561-599.

Kohler, P. and Huth, A. (1998). The effects of tree species grouping in tropical rainforest modelling: Simulations with the individual-based model, *Ecological Modelling* 109(3): 301-321.

Kolstrom, M. (1998). Ecological simulation model for studying diversity of stand structure in boreal forests, *Ecological Modelling* 111(1): 17-36.

Kurpick, P., Kurpick, U. and Huch, A. (1997). The influence of logging on a Malaysian Dipterocarp rain forest: a study using a forest gap model, *Journal of Theoretical Biology* 185(1): 47-54.

Copyright by Mahidol University

Liu, J. and Ashton, P. S. (1995). Individual-based simulation models for forest succession and management, *Forest Ecology and Management* 73(1-3): 157-175.

Malanson, G. P. (1996). Effects of dispersal and mortality on diversity in a forest stand model, *Ecological Modelling* 87: 103–110.

Matthews, R. B. and Pilbeam, C. (2005). Modelling the long-term productivity and soil fertility of maize/ millet cropping systems in the mid-hills of Nepal, *Agriculture, Ecosystem and Environment* 111(1-4): 119-139.

Mishra, H. R. (1982). Balancing human needs and conservation in Nepal's Royal Chitwan National Park, *Ambio* 11(5): 246–252.

Mohren, G. M. J., Hees van, A. F. M. and Bartelink, H. H. (1991). Succession models as an aid for forest management in mixed stands in The Netherlands, *Forest Ecology and Management* 42(1–2): 111–128.

Nagendra, H. (2002). Tenure and forest conditions: community forestry in the Nepal Terai. *Environmental Conservation* 29(4): 530-539.

Nagendra, H., Tucker, C., Carlson, L., Southworth, J., Karmacharya, M.and Karna, B. (2004). Monitoring parks through remote sensing: Studies in Nepal and Honduras, *Environmental Management* 34(5): 748-760.

NPC. (1995). Nepal agricultural perspective plan, main document, Agricultural Project Service Center, Kathmandu and John Meller Associates Inc. Washington D. C., National Planning Commission Nepal, pp. 282.

Odum, H. T. (1970). An emerging view of the ecological system at El Verde. A tropical rain forest: a study of irradiation and ecology at El Verde, Puerto Rico. Odum, H. T. and Pigeon, R. F. Virginia, National Technical Information Service**:** I-191-277.

Pandey, S. K. and Shukla, R. P. (2003). Plant diversity in managed sal (*Shorea robusta* Gaertn.) forests of Gorakhpur, India: species composition, regeneration and conservation, *Biodiversity and Conservation* 12(11): 2295-2319.

Phipps, R. L. (1979). Simulation of wetlands forest vegetation dynamics, *Ecological Modeling* 7: 257–288.

Copyright by Mahidol University

Prentice, I. C. and Helmisaari, H. (1991). Silvics of north European trees: compliation, comparison and implications for forest succession modelling, *Forest Ecology and Management* 42: 79-93.

Rautiainen, O. (1999). Spatial yield model for *Shorea robusta* in Nepal. *Forest ecology and Management* 119: 151-162.

Rautiainen, O., Pukkala, T. and Miina, J. (2000). Optimizing the management of even-aged *Shorea robusta* stands in southern Nepal using individual tree growth models. *Forest Ecology and Management* 126: 417-426.

Rautiainen, O. and Suoheimo, J. (1997). Natural regeneration potential and early development of *Shorea robustu* Gaertn.f. forest after regeneration felling in the Bhabar-Terai zone in Nepal. *Forest Ecology and Management* 92: 243-251.

Reynolds, J. F., Bugmann H. and Pitelk L. F. (2001). How much physiology is needed in forest gap models for simulating long-term vegetation response to global change? challenges, limitations, and potentials, *Climatic Change* 51: 541–557.

Risch, A. C., Heiri, C. and Bugmann, H. (2005). Simulating structural forest patterns with a forest gap model: a model evaluation, *Ecological Modelling*, 181(1-2): 161-172.

Roachanakanan, R. (2002). Predicting the dynamics of rainforests in Australia, Research School of Biological Science, Institute of Advance Studies, Canberra, The Australian National University: pp 178.

Rohlf, F. J. and Davenport, D. (1969). Simulation of simple models of animal behavior with a digital computer, *Journal of Theoretical Biology*, 23: 400–424.

Seagle, S. W. and Liang, S. Y. (2001). Application of a forest gap model for prediction of browsing effects on riparian forest succession, *Ecological Modelling* 144(2-3): 213-229.

Shepherd, Gill. (2004). The ecosystem approach: five steps to implementation, IUCN, Gland, Switzerland and Cambridge, UK, pp 30.

Shrestha, B. K. and Dangol, D. R. (2006). Change in grassland vegetation in the northern part of Royal Chitawan National Park, Nepal, *Scientific World*, 4:4

Copyright by Mahidol University

Shrestha, K. K. and Jha, P. K. (1997). Plant diversity and evaluation of conservation measures in the Royal Bardia National Park (RBNP), A report submitted to World Wildlife Fund Nepal Program, Kathmandu, Nepal.

Shrestha, M. K. (2004). Relative ungulate abundance in a fragmented landscape: Implications for tiger conservation, University of Minnesota. Ph.D. Thesis.

Shugart, H. H. (1984). A theory of forest dynamics, Springer-Verlag, New York, pp 278.

Shugart, H. H. (1998). Terrestrial ecosystems in changing environments, Cambridge University Press, Cambridge, pp 564.

Shugart, H. H. (2003). The ecological implication of forest succession models, New York, pp 298.

Shugart, H. H. (2002). The forest gap model, earth system: biological and ecological dimensions of global environmental change. John Wiley & Sons, Ltd, Chichester.

Shugart, H. H. and West, D. C. (1977). Development of an Appalachian decidious forest succession model and its application to assessment of the impact of the chestnut blight, *Journal of Environmental Management* 5: 161-179.

Shugart, H. H., Hopkins, M. S., Burgess, I. P., and Mortlock, A. T. (1980). The development of a succession model for subtropical rain forest and its application to assess the effects of timber harvests at Wiangaree State Forest, New South Wales, *Journal of Environmental Management* 11: 243-265.

Shugart, H. H. and Smith, T. M. (1996). A review of forest patch models and their application to global change research, *Climatic Change* 34(2): 131-153.

Singh, A., Reddy, V. S., Singh, J. S., (1995). Analysis of woody vegetation of Corbett National Park, India. *Vegetation* 120: 69–79.

Stainton, J. D. A. (1972). Forest of Nepal, John Murryy, London.

Straede S., Nebel, G., Rijal, A. (2002). Structure and floristic composition of community forests and their compatibility with villagers'traditional needs for forest products, *Biodiversity and Conservation* 11: 487–508.

Copyright by Mahidol University

Strasser, M. J. (1992). Computer modeling of montane eucalypt forests, Research School of Biological Sciences, The Australian National University, Canberra, pp 347.

Timilsina, N. (2005). Analysis of forest under different management regime in the western Terai of Nepal and its relation to environment and human use, Environmental studies, Collage of art and Science, Miami, Florida, Florida International University, Master's Thesis.

Timilsina, N., Ross, M. S. and Heinen J. T. (2007). Community analysis of Sal (*Shorea robusta*) forest in the western Terai of Nepal, *Forest Ecology and Management* 241(1-3): 223-234.

Tiwari, D. (1995). A monograph on sal (*Shorea robusta* Gaertn.f), Dehraadun, India, International Book Distributors.

Troup, R. S. (1921). The silviculture of Indian trees, Volumes I, II and III, Oxford at the Clarendon press.

UNEP, (1997). Chitawan National Park, United Nations Environment Programme, World Conservation Monitoring Centre, (http://www.unep-wcmc.org/sites/wh/chitwan.html, accessed on June16th, 2007).

Urban, D. L. and Shugart, H. H. (1992), Individual-based models of forest succession, theory and prediction, London, Chapman and Hall, *Plant succession*: 249-292.

Webb, E. L. and Sah, R. N. (2003). Structure and diversity of natural and managed Sal (*Shorea robusta* Gaertn .f.) forest in the Terai of Nepal, *Forest ecology and Management* 176 (1-3): 337-353.

Wesche, K. (1997). A classification of a tropical sal (*Shorea robusta)* forest stand in southern Nepal, *Phytocoenologia* 27, 103–118.

Young, T. P. and Hubbell, S. P. (1991). Crown asymmetry, tree falls, and repeat disturbance of broad-leaved forest gaps, *Ecology* 27(4): 1464-1471.

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APPENDIX

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Appendix-A

Tree measurement form

(This form was used in sampling plot for tree measurement)

Name of the data recorder: …… Date of record taken:

Name of the Sal Forest Block: ……

Types of the Forest: Mature sal forest/Successional forest/ Disturbed forest

Block sal Forest Area ……..Ha, Block no/ Strata No……

Sample plot No…… , Size of the sample plot …… ……., Age of the stand ……..

Position of the plot (RP)……

Soil types (physical outlook) ……..

Special event and other remarkable or important information found in the plot or found by discussion in team

……
……
……
……
……

SN	Species	Trees (>1.27cm DBH)		Remarks
		DBH (cm)	Heght (m)	
1				
2				
3				
4				
5				
6				
7				
8				
9				
10				
11				
12				
13				
14				
15				
16				
17				
18				
19				
20				

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Appendix-B
Checklist for local consultation/ discussion in the sample plot

Target respondent: Local people**,** Forester, Botanist	**Venue:** Selected sample plot
Number of respondent: 5-10 people every day	**Time:** During the measurement

For Objective-1 (Existing floristic structure and composition of sal forest)

- Why this forest/plot is considered mature sal forest? Whether this sampled forest /plot is representation of other mature forest in this national park? If no, what is the over view of composition and structure of not represented mature forest?.
- What was the composition and structure of sampled forest before 10 years? Is it is changing?

For Objective-2 (Re-parameterization of the KIAMBRAM model)

- D_{max}, H_{max}, Age_{max} for the selected [1] species.
- Tree phenology, seed longevity, seed dispersal agent and types of soil required seedling establishment for selected tree species.
- Windfall frequency in the forest and its impact (percentages of tree fall) in the stand.

For Objective-3 (Test of the model)

- What is the tentative age of this stand? What was the condition (structure and composition) of this forest at the very early stages?
- Wherether any big disturbances was occured during last 20 years?, When?, What types?, How much trees were loss or how much big sized trees were able to survive? What is the implication of these types of disturbances for growth and development of the sal forest stand?
- If such types of big disturbances is occurs, what types of species are generally introducing and establishing at very early stages?, what composition will be changes with respect to different time period and at what condition it will occurs?
- What will be the last condition of this forest (climax stage) if it will keep at similar condition with out any disturbances? Why ?

[1] For those species whose parameters neither avilable in literatures nor explained by experts.

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Appendix-C (I): Stem density of all the species in site-1 (mature forest)

SN	Species	Local name	Plot-1	Plot-2	Plot-3	Plot-4	Plot-5	Plot-6	Plot-7	Plot-8	Plot-9	Plot-10	Stems/ha
1	*Actinodaphne angusifolia*	Jakrikath					1			3	3	1	16
2	*Albizia lebbeck*	Tapria sirish						1	1	1			6
3	*Aporusa octandra*	Hade kaulo								1			2
4	*Bridelia retusa*	Gayo			1	1				1			6
5	*Buchanania latifolia*	Piyari			1								2
6	*Cassine glauca*	Putalikath									1		2
7	*Carpesium nepalense*	Padke				1							2
8	*Cleistocalyx operculatus*	Camuna		7	7	7	3		9	21	3	14	142
9	*Dalbergia latifolia*	Satisal										1	2
10	*Dillenia pentagyna*	Tatari		8	6	2	4	2	6	2	13	5	96
11	*Diospyros malabarica*	Tenju								1			2
12	*Duabanga grandiflora*	Lampate		1									2
13	*Garuga pinnata*	Dagdabe	1						1			1	6
14	*Grewia optiva*	Bhimal									1		2
15	*Holarrhena pubescens*	Ban Khirro								2	2	2	12
16	*Lannea coromandelica*	Jinjar								2			4
17	*Largerstroemia parviflora*	Boddhayaro	3	1	4	1		11	2	3		1	52
18	*Litsea monopetala*	Kutmero			4		15	1		30	2	2	108
19	*Mallotus philippensis*	Sindhure		1						5			12
20	*Myrsine semiserrata*	Kalikath			1			2					6
21	*Phyllanthus emblica*	Amala		1	2	2		1					12
22	*Shorea robusta*	Sal	27	8	3	2	6	4	3	20	4	5	164
23	*Terminalia bellirica*	Barro	1										2
24	*Trewia nudiflora*	Gutel								1			2
	Plot -total		32	27	29	16	29	22	22	93	29	32	
	Per hectare		**640**	**540**	**580**	**320**	**580**	**440**	**440**	**1860**	**580**	**640**	**662**

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Appendix-C (II): Basal area of all the species in site-1 (mature forest)

SN	Species	Local name	Plot-1	Plot-2	Plot-3	Plot-4	Plot-5	Plot-6	Plot-7	Plot-8	Plot-9	Plot-10	BA/ha
1	*Actinodaphne angusifolia*	Jakrikath					0.001			0.002	0.007	0.001	0.022
2	*Albizia lebbeck*	Tapria sirish						0.001	0.001	0.011			0.026
3	*Aporusa octandra*	Hade kaulo								0.001			0.002
4	*Bridelia retusa*	Gayo			0.008	0.01				0.001			0.038
5	*Buchanania latifolia*	Piyari			0.01								0.020
6	*Cassine glauca*	Putalikath									0.001		0.002
7	*Carpesium nepalense*	Padke				0.001							0.002
8	*Cleistocalyx operculatus*	Camuna		0.257	0.26	0.27	0.09		0.134	0.18	0.006	0.172	2.738
9	*Dalbergia latifolia*	Satisal										0.003	0.006
10	*Dillenia pentagyna*	Tatari		0.018	0.113	0.131	0.011	0.050	0.043	0.04	0.015	0.007	0.857
11	*Diospyros malabarica*	Tenju								0.001			0.002
12	*Duabanga grandiflora*	Lampate		0.024									0.048
13	*Garuga pinnata*	Dagdabe	0.028						0.08			0.003	0.222
14	*Grewia optiva*	Bhimal									0.042		0.084
15	*Holarrhena pubescens*	Ban Khirro								0.003	0.017	0.006	0.052
16	*Lannea coromandelica*	Jinjar								0.001			0.002
17	*Largerstroemia parviflora*	Boddhayaro	0.188	0.027	0.11	0.002		0.315	0.038	0.004		0.001	1.370
18	*Litsea monopetala*	Kutmero			0.006		0.017	0.001		0.03	0.002	0.004	0.119
19	*Mallotus philippensis*	Sindhure		0.001						0.003			0.008
20	*Myrsine semiserrata*	Kalikath			0.002			0.002					0.008
21	*Phyllanthus emblica*	Amala		0.003	0.003	0.01		0.004					0.040
22	*Shorea robusta*	Sal	1.34	1.66	0.006	0.33	1.261	0.764	1.041	2.2	1.041	1.479	22.244
23	*Terminalia bellirica*	Barro	0.04										0.080
24	*Trewia nudiflora*	Gutel								0.001			0.002
	Plot -total		1.596	1.99	0.518	0.754	1.38	1.136	1.337	2.478	1.131	1.676	
	Per hectare		**31.92**	**39.8**	**10.36**	**15.08**	**27.6**	**22.73**	**26.74**	**49.56**	**22.62**	**33.52**	**27.99**

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Appendix-D (I): Stem density of all the species in site-2 (mature forest)

SN	Species	Local name	Plot-11	Plot-12	Plot-13	Plot-14	Plot-15	Plot-16	Plot-17	Plot-18	Plot-19	Plot-20	Stem/ha
1	*Actinodaphne angusifolia*	Jhakrikath							1				2
2	*Adina cordifolia*	Haldu										3	6
3	*Anthocephalus chinensis*	Kadam								5			10
4	*Aporusa octandra*	Hade							19	9	1		58
5	*Bauhinia purpurea*	Tanki		2	1	1	5				1		20
6	*Bischofia Javanica*	Kainjal							1				2
7	*Bombax ceiba*	Simal									1		2
8	*Butea monosperma*	Palas								2			4
9	*Careya arborea*	Kumhi	1						1	1			6
10	*Casearia graveolens*	Deri		2		4							12
11	*Cassia fistula*	Rajbriksha								1	1		4
12	*Cleistocalyx operculatus*	Camuna	1	8	7	9			3	6	1	7	84
13	*Cornus oblonga*	Latikath								1			2
14	*Desmodium oojeinense*	Sadhan										1	2
15	*Dillenia pentagyna*	Tatari	9	13	10	13			13	12	1	1	144
16	*Diospyros malabarica*	Tenju							1	1	1	1	8
17	*Ehretia wallichiana*	Bohari							2	4	1		14
18	*Glochidion velutinum*	Mahuwa								2			4
19	*Holarrhena pubescens*	Ban Khiro	2	1	1	5	8		11	13	1	2	88
20	*Lannea coromandelica*	Jinjar				1			1				4
21	*Largerstroemia parviflora*	Boddhayaro	2	2	6	4	5			1			40
22	*Litsea monopetala*	Kutmero	14	17	9	12	2		11	14		2	162
23	*Mallotus philippensis*	Sindhure	1		1	12			3	14			62
24	*Myrsine semiserrata*	Kalikath				1							2
25	*Phyllanthus emblica*	Amala				1							2
26	*Randia dumetorum*	Main dal								1			2
27	*Semecarpus anacardium*	Bhalayo								5			10
28	*Shorea robusta*	Sal	12	5	8	26	7	17	19	15	20	12	282
29	*Syzygium cumini*	Jamun							2	1	1		8
30	*Terminalia bellirica*	Barro				1					5	1	14
31	*Terminalia chebula*	Harro								1			2
32	*Trewia nudiflora*	Gutel						1	6	1			16
33	*Xeromphis dumetorum*	Pedar						4					8
	Plot wise total		42	50	43	90	27	22	94	110	35	30	1086
	Plot wise per hactare		**840**	**1000**	**860**	**1800**	**540**	**440**	**1880**	**2200**	**700**	**600**	

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Appendix-D (II): Basal area of all the species in site-2 (mature forest)

SN	Species	Local name	Plot-11	Plot-12	Plot-13	Plot-14	Plot-15	Plot-16	Plot-17	Plot-18	Plot-19	Plot-20	BA/ha
1	*Actinodaphne angusifolia*	Jhakrikath							0.008				0.016
2	*Adina cordifolia*	Haldu										0.114	0.228
3	*Anthocephalus chinensis*	Kadam								0.004			0.008
4	*Aporusa octandra*	Hade							0.02	0.02	0.003		0.086
5	*Bauhinia purpurea*	Tanki		0.002	0.001	0.013	0.015				0.002		0.066
6	*Bischofia Javanica*	Kainjal							0.11				0.220
7	*Bombax ceiba*	Simal									0.13		0.260
8	*Butea monosperma*	Palas								0.002			0.004
9	*Careya arborea*	Kumhi	0.007						0.007	0.004			0.036
10	*Casearia graveolens*	Deri		0.002		0.076							0.156
11	*Cassia fistula*	Rajbriksha								0.001	0.0004		0.003
12	*Cleistocalyx operculatus*	Camuna	0.001	0.088	0.036	0.407			0.03	0.015	0.004	0.017	1.196
13	*Cornus oblonga*	Latikath								0.001			0.002
14	*Desmodium oojeinense*	Sadhan										0.122	0.244
15	*Dillenia pentagyna*	Tatari	0.038	0.063	0.033	0.104			0.05	0.018	0.001	0.001	0.616
16	*Diospyros malabarica*	Tenju							0.029	0.001	0.007	0.032	0.138
17	*Ehretia wallichiana*	Bohari							0.003	0.01	0.003		0.032
18	*Glochidion velutinum*	Mahuwa								0.002			0.004
19	*Holarrhena pubescens*	Ban Khiro	0.012	0.001	0.0004	0.044	0.026		0.1	0.641	0.002	0.002	1.657
20	*Lannea coromandelica*	Jinjar				0.001			0.001				0.004
21	*Largerstroemia parviflora*	Boddhayaro	0.003	0.034	0.003	0.004	0.01			0.007			0.122
22	*Litsea monopetala*	Kutmero	0.016	0.02	0.012	0.019	0.002		0.01	0.016		0.005	0.200
23	*Mallotus philippensis*	Sindhure	0.003		0.004	0.034			0.006	0.016			0.126
24	*Myrsine semiserrata*	Kalikath				0.0004							0.001
25	*Phyllanthus emblica*	Amala				0.001							0.002
26	*Randia dumetorum*	Main dal								0.004			0.008
27	*Semecarpus anacardium*	Bhalayo								0.006			0.012
28	*Shorea robusta*	Sal	1.185	1.046	0.92	0.27	1.655	1.07	0.77	0.541	1.156	1.271	19.768
29	*Syzygium cumini*	Jamun							0.001	0.0004	0.003		0.009
30	*Terminalia bellirica*	Barro				0.08					0.225	0.003	0.616
31	*Terminalia chebula*	Harro								0.003			0.006
32	*Trewia nudiflora*	Gutel						0.001	0.02	0.001			0.044
33	*Xeromphis dumetorum*	Pedar						0.036					0.072
	Plot wise total		1.27	1.26	1.01	1.05	1.71	1.11	1.17	1.31	1.54	1.57	25.96
	Plot wise per hactare		**25.3**	**25.12**	**20.17**	**21.07**	**34.16**	**22.14**	**23.3**	**26.27**	**30.73**	**31.34**	

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Appendix-E

Summary of basal area and stem density of the mature sal forest

SN	Species	Local name	Stem density		Basal area	
			No /ha	Percentages (RA)	m^2/ha	Percentages (RA)
1	*Shorea robusta*	Sal	223	25.51	21.006	77.855
2	*Litsea monopetala*	Kutmero	135	15.45	0.16	0.593
3	*Dillenia pentagyna*	Tatari	120	13.73	0.737	2.732
4	*Cleistocalyx operculatus*	Camuna	113	12.93	1.967	7.290
5	*Holarrhena pubescens*	Ban Khiro	50	5.72	0.855	3.169
6	*Largerstroemia parviflora*	Boddhayaro	46	5.26	0.746	2.765
7	*Mallotus philippensis*	Sindhure	37	4.23	0.067	0.248
8	*Aporusa octandra*	Hade	30	3.43	0.044	0.163
9	*Bauhinia purpurea*	Tanki	10	1.14	0.033	0.122
10	*Trewia nudiflora*	Gutel	9	1.03	0.023	0.085
11	*Actinodaphne angusifolia*	Jhakrikath	9	1.03	0.019	0.070
12	*Terminalia bellirica*	Barro	8	0.92	0.348	1.290
13	*Phyllanthus emblica*	Amala	7	0.80	0.021	0.078
14	*Ehretia wallichiana*	Bohari	7	0.80	0.016	0.059
15	*Casearia graveolens*	Deri	6	0.69	0.078	0.289
16	*Diospyros malabarica*	Tenju	5	0.57	0.07	0.259
17	*Semecarpus anacardium*	Bhalayo	5	0.57	0.006	0.022
18	*Anthocephalus chinensis*	Kadam	5	0.57	0.004	0.015
19	*Syzygium cumini*	Jamun	4	0.46	0.005	0.019
20	*Myrsine semiserrata*	Kalikath	4	0.46	0.005	0.019
21	*Xeromphis dumetorum*	Pedar	4	0.46	0.036	0.133
22	*Lannea coromandelica*	Jinjar	4	0.46	0.003	0.011
23	*Adina cordifolia*	Haldu	3	0.34	0.114	0.423
24	*Garuga pinnata*	Dagdabe	3	0.34	0.111	0.411
25	*Bridelia retusa*	Gayo	3	0.34	0.019	0.070
26	*Careya arborea*	Kumhi	3	0.34	0.018	0.067
27	*Albizia lebbeck*	Kalo sirish	3	0.34	0.013	0.048
28	*Butea monosperma*	Palas	2	0.23	0.002	0.007
29	*Glochidion velutinum*	Mahuwa	2	0.23	0.002	0.007
30	*Cassia fistula*	Rajbriksha	2	0.23	0.002	0.007
31	*Bombax ceiba*	Simal	1	0.11	0.13	0.482
32	*Desmodium oojeinense*	Sadhan	1	0.11	0.122	0.452
33	*Bischofia Javanica*	Kainjal	1	0.11	0.11	0.408
34	*Grewia optiva*	Bhimal	1	0.11	0.042	0.156
35	*Duabanga grandiflora*	Lampate	1	0.11	0.024	0.089
36	*Buchanania latifolia*	Piyari	1	0.11	0.01	0.037
37	*Randia dumetorum*	Main dal	1	0.11	0.004	0.015
38	*Dalbergia latifolia*	Satisal	1	0.11	0.003	0.011
39	*Terminalia chebula*	Harro	1	0.11	0.003	0.011
40	*Cassine glauca*	Putalikath	1	0.11	0.001	0.004
41	*Carpesium nepalense*	Padke	1	0.11	0.001	0.004
42	*Cornus oblonga*	Latikath	1	0.11	0.001	0.004
	Total		**874**	**100**	**26.981**	**100**

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Appendix-F

Canopy height computation

	Species	Observed maximum Ht (m)	Respective DBH		Species	Observed maximum Ht (m)	Respective DBH
1	*Shorea robusta*	23.00	49.30	11	*Shorea robusta*	31.00	59.80
	Shorea robusta	25.00	43.40		*Shorea robusta*	30.50	56.70
	Shorea robusta	27.50	41.10		*Shorea robusta*	30.00	43.30
	Average	25.17			Average	30.50	
2	*Shorea robusta*	28.00	56.30	12	*Shorea robusta*	33.50	73.90
	Shorea robusta	25.50	61.40		*Shorea robusta*	31.00	57.60
	Shorea robusta	31.50	71.90		*Shorea robusta*	29.00	50.30
	Average	28.33			Average	31.17	
3	*C. operculatus*	15.50	27.10	13	*Shorea robusta*	33.00	55.70
	L.parviflora	15.00	21.90		*Shorea robusta*	29.50	52.50
	L.parviflora	15.00	19.10		*Shorea robusta*	32.00	56.70
	Average	15.17			Average	31.50	
4	*Shorea robusta*	29.00	63.70	14	*Shorea robusta*	31.50	55.40
	C. operculatus	13.00	31.80		*C. operculatus*	24.00	50.90
	D. pentagyna	12.00	38.80		*T. bellirica*	26.00	31.83
	Average	18.00			Average	27.17	
5	*Shorea robusta*	28.00	54.40	15	*Shorea robusta*	33.50	71.30
	Shorea robusta	34.50	76.40		*Shorea robusta*	31.00	55.70
	Shorea robusta	29.50	57.30		*Shorea robusta*	32.50	58.90
	Average	30.67			Average	32.33	
6	*Shorea robusta*	36.00	89.80	16	*Shorea robusta*	27.00	42.00
	L.parviflora	18.00	21.30		*Shorea robusta*	26.00	35.60
	L.parviflora	18.00	25.80		*Shorea robusta*	26.50	37.90
	Average	24.00			Average	26.50	
7	*Shorea robusta*	37.50	91.70	17	*Shorea robusta*	36.00	67.80
	Shorea robusta	31.50	54.10		*Shorea robusta*	36.50	69.70
	Shorea robusta	28.50	43.90		*D. malabarica*	12.00	19.10
	Average	32.50			Average	28.17	
8	*Shorea robusta*	33.75	71.60	18	*Shorea robusta*	37.50	81.80
	Shorea robusta	34.00	75.80		*H. pubescens*	23.00	87.50
	Shorea robusta	36.00	76.40		*L. monopetala*	7.50	2.90
	Average	34.58			Average	22.67	
9	*Shorea robusta*	34.00	57.90	19	*Shorea robusta*	33.00	50.60
	Shorea robusta	36.40	68.10		*Shorea robusta*	27.00	38.50
	Shorea robusta	35.50	63.70		*Shorea robusta*	28.00	43.00
	Average	35.30			Average	29.33	
10	*Shorea robusta*	39.00	96.10	20	*Shorea robusta*	38.50	90.70
	Shorea robusta	36.00	66.50		*Shorea robusta*	27.50	39.50
	Shorea robusta	31.50	64.30		*Shorea robusta*	28.50	47.70
	Average	35.50			Average	31.50	

Note: Among the 60 trees only 51 (except highlighted part) were under taken for top canopy height computation because of 9 trees found out of criteria (less than 20 m height)

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Appendix-G

List of tree species prepaed before field verification

	Name	Family	Local name
1	*Acacia catechu*	Leguminosae	Khair
2	*Adina cordifolia*	Rubiaceae	Haldu
3	*Aegle marmelos*	Rutaceae	Bel
4	*Albizia lebbeck*	Leguminosae	Kalo Sirish
5	*Anogeissus latifolius*	Combretaceae	Banjhi
6	*Anthocephalus chinensis*	Rubiaceae	Kadam
7	*Bauhinia variegata*	Caesalpiniaceae	Koiralo
8	*Bombax ceiba*	Leguminosae	Simal
9	*Buchanania latifofolia*	Anacardiaceae	Chirauji (piyari)
10	*Butea monosperma*	Leguminosae	Palas
11	*Careya arborea*	Lecythidanceae	Kumhi
12	*Cassia fistula*	Leguminosae	Rajbriksha
13	*Carpesium nepalense*	Linnaea	Padke
14	*Cedrela toona*	Leguminosae	Tooni
15	*Dalbergia latifolia*	Papilionaceae	Satisal
16	*Dalbergia sissoo*	Leguminosae	Sissoo
17	*Dillenia pentagyna*	Dilleniaceae	Tatari
18	*Desmodium oojeinense*	Leguminosae	Sadhan
19	*Ficus beghalensis*	Rubiaceae	Bayar
20	*Glochidion velutinum*	Euphorbiaceae	Mahuwa
21	*Holarrhena pubescens*	Apocynaaceae	Indrajau
22	*Largerstroemia parviflora*	Lythraceae	Bod dhayaro
23	*Litsea monopetala*	Lauraceae	Kutmero
24	*Mallotus philippensis*	Euphorbiaceae	Sindhure
25	*Myrsine semiserrata*	Myrsinaceae	Kalikath
26	*Phyllanthus emblica*	Euphorbiaceae	Amala
27	*Pterocarpus marsupium*	Leguminosae	Bijaya sal
28	*Schleichera oleosa*	Sapindaceae	Kusum
29	*Semecarpus anacardium*	Anacardiaceae	Bhalayo
30	*Shorea robusta*	Dipterocarpaceae	Sal
31	*Syzygium cumini*	Myrtaceae	Jamun
32	*Terminalia alata*	Combretaceae	Asna
33	*Terminalia bellirica*	Combretaceae	Barro
34	*Terminalia chebula*	Combretaceae	Harro
35	*Trewia nudiflora*	Euphorbiaceae	Gutel

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Appendix-H

List of tree species collected from different sites

	Species	Family name	Local name	Collected from
1	*Acacia catechu*	Leguminosae	Khair	Site -3
2	*Actinodaphne angusifolia*	Lauraceae	Jhakri Kath	
3	*Adina cordifolia*	Rubiaceae	Haldu	
4	*Aegle marmelos*	Rutaceae	Bel	Site -3
5	*Albizia lebbeck*	Leguminosae	Kalo Sirish	
6	*Anogeissus latifolius*	Combretaceae	Banjhi	Site -3 and site-4
7	*Anthocephalus chinensis*	Rubiaceae	Kadam	
8	*Aporusa octandra*	Euphorbiaceae	Hade	
9	*Bauhinia purpurea*	Caesalpiniaceae	Tanki	Site-3 and site-4
10	*Bauhinia variegata*	Caesalpiniaceae	Koiralo	
11	*Bischofia javanica*	Staphyleaceae	Kainjal	
12	*Bombax ceiba*	Leguminosae	Simal	
13	*Bridelia retusa*	Euphorbiaceae	Gayo	
14	*Buchanania latifolia*	Anacardiaceae	Piyari	
15	*Butea monosperma*	Leguminosae	Palas	
16	*Careya arborea*	Lecythidanceae	Kumhi	
17	*Casearia graveoles*	Salicaceae	Deri	
18	*Cassia fistula*	Leguminosae	Rajbriksha	
19	*Cassine glauca*	Caesalpiniaceae	Putali kath	
20	*Carpesium nepalense*	Linnaea	Padke	
21	*Cedrela toona*	Leguminosae	Tooni	Site -3 and site-4
22	*Cleistocalyx operculatus*	Myrtaceae	Camuna	
23	*Cornus oblonga*	Cornaceae	Lati Kath	
24	*Dalbergia latifolia*	Papilionaceae	Satisal	
25	*Dalbergia sissoo*	Leguminosae	Sissoo	Site-3
26	*Desmodium oojeinense*	Leguminosae	Sadhan	
27	*Dillenia pentagyna*	Dilleniaceae	Tatari	
28	*Diospyros malabarica*	Ebenaceae	Teju	
29	*Duabanga grandiflora*	Sonneratiaceae	Lampate	
30	*Ehretia wallichiana*	Cordiaceae	Bohari	
31	*Ficus beghalensis*	Rubiaceae	Bayar	Site-3
32	*Ficus benjamina*		Dumbri	Site-4
33	*Garuga pinnata*	Burseraceae	Dabdabe	
34	*Glochidion velutinum*	Euphorbiaceae	Mahuwa	
35	*Grewia optiva*	Tiliaceae	Bhimal	
36	*Gmelina arborea*	Verbenaceae	Khamari	Site-3
37	*Holarrhena pubescens*	Apocynaaceae	Indrajau	
38	*Hymenodictyon excelsum*		Bhurkul	Site-3 and site-4
39	*Largerstroemia parviflora*	Lythraceae	Bod dhayaro	
40	*Lannea coromandelica*	Anacardiaceae	Jinjar	
41	*Litsea monopetala*	Lauraceae	Kutmero	
42	*Mallotus philippensis*	Euphorbiaceae	Sindhure	
43	*Myrsine semiserrata*	Myrsinaceae	Kalikath	
44	*Phyllanthus emblica*	Euphorbiaceae	Amala	
45	*Pterocarpus marsupium*	Leguminosae	Bijaya sal	Site-3 and site-4
46	*Randia dumetorum*	Rubiaceae	Maindal	
47	*Schleichera oleosa*	Sapindaceae	Kusum	Site-3 and site-4
48	*Semecarpus anacardium*	Anacardiaceae	Bhalayo	
49	*Shorea robusta*	Dipterocarpaceae	Sal	
50	*Syzygium cumini*	Myrtaceae	Jamun	
51	*Terminalia alata*	Combretaceae	Asna	Site-3 and site-4
52	*Terminalia bellirica*	Combretaceae	Barro	
53	*Terminalia chebula*	Combretaceae	Harro	
54	*Trewia nudiflora*	Euphorbiaceae	Gutel	
55	*Xeromphis utiginosa*	Rubiaceae	Pedar	

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Appendix-I

Methodology used for computation of maximum observed diameter increment (∂D_{max}) and tree growth table

Here, example is ellustrated for *Acacia catechu.*

Major Problems:

- Preparation of diameter growth table
- Computation ∂D_{max}

Known values:

- D_{max} = 50cm {collected from different sources described in 4.2.2.1 (a)}
- H_{max} = 2300cm {from different sources described in 4.2.2.1 (a)}
- 20^{th} years growth information , dbh =19 cm and Height = 16.2 m (Jackson, 1994, p343)

Supposed value: Initial dbh of the tree =1cm (dbh at the end of the year 1)

Supportive formulas:

$$G_{\partial Dmax} \cong 5H_{max}\left(\frac{\partial D_{max}}{D_{max}}\right).....(1)$$

$$b_2 = \frac{2(H\,max - 137)}{D\,max}.....(2) \quad \text{and} \quad b_3 = \frac{(H_{max} - 137)}{D^2_{max}}.....(3)$$

$$H = 137 + b_2 D - b_3 D^2 ..... (4)$$

$$\frac{\partial D}{\partial t} = \frac{\{GD\,(1 - \frac{DH}{Dmax\ Hmax})\}}{(274 + 3b_2 D - 4b_3 D^2)}..... ...(5)$$

Computation process:

Steps	Process	Ilustration
Step 1	Choose approximate value of ∂D_{max}	Suppose ∂D_{max} =1cm
Step 2	Compute G value using formula -1.	G = 5*2300*1/(50)=230.
Step 3	Compute b_2 and b_3 using formula 2 and 3	$b_2 = \frac{2(2300-137)}{50} = 86.52$ & $b_3 = \frac{(2300-137)}{50*50} = 0.865$

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Methodology used in computation of ∂D_{max} and growth table (cont.)

Step 4 : Make diameter growth table formate

Year	Diameter	Height	Diameter increment
1	1	223*	0.43
2	1.43	259	0.51
3			
…			
….			
20	15.2	1253	0.85

- **1st coloum:** field 1 to 20 because in this case 20th year s growth data is available
- **2nd column**: is placed 1 for first year.
- **3rd colum**: computed using formula -3.

Then height of the first year
= 137 + 86.52*1-.865*(1)^2= 223 cm*. (using b_2= 86.5, b_3 = 0.865 and D=1 for year 1)

- **4th column** (for 1st year): $\frac{\{GD\,(1-\frac{DH}{Dmax\ Hmax})\}}{(274+3b_2D-4b_3D^2)} = \frac{\{230*1(1-\frac{1*223}{50*2300})\}}{(274+3*86.5*1-4_{*.865*1*1})} = 0.43$

At 2nd year :
- Diameter = 1+0.43=1.43
- Height =259 (same procedure of computation)
- Diameter increment =0.51.

Similarly, at 20th year
- Diameter =15.2
- Height =1253
- Diameter increment =0.85

Step 5 : Check the computed value with known value

Recoded value found computed value. Therefore chooseed ∂D_{max} value shoude change.

Step 6 : Repeate all the steps with new ∂D_{max} values (step 1 to 5).

Then ∂D_{max} =2.0 were choosed. Then similar process were repeted. It gives dbh=30.1cm and Ht= 1956cm for year 20. Both of the values were higher than recorded value , therefore this ∂D_{max} was also not appropriate. Similary other values between 1.0-2.0 were also choose many times and finally 1.4 gave closed result for year 20. Then the table was extended upto year 117 because at this year tree reached at maximum diameter 50cm and maximum height 2300cm after that growth of the tree wawas stops.

Computed growth table is presented in next page. Table shows, calculated dbh was matched at year 18 but height is matched at year 20. It was really to adjust both of the value at the same time. This is may be due to dfferences between diameter- height ratio of the measured tree and D_{max} and H_{max} ratio of our data set.

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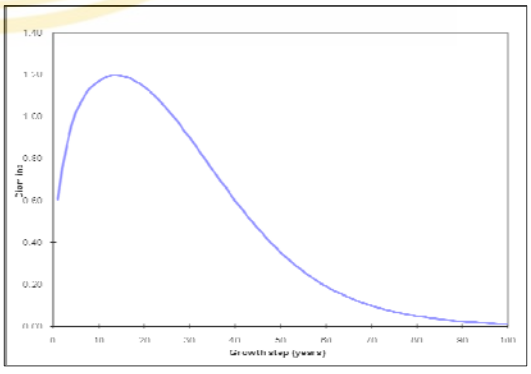
Computed growth table for *Acacia catechu*

Year	Diam	Ht	Dia. Incre.	Year	Diam	Ht	Dia. incre.	Year	Diam	Ht	Dia. incre.
1	1.0	223	0.61	41	40.1	2216	0.57	81	49.3	2300	0.05
2	1.6	274	0.76	42	40.7	2226	0.54	82	49.4	2300	0.04
3	2.4	337	0.87	43	41.3	2234	0.52	83	49.4	2300	0.04
4	3.2	408	0.96	44	41.8	2242	0.49	84	49.5	2300	0.04
5	4.2	484	1.02	45	42.3	2248	0.47	85	49.5	2300	0.03
6	5.2	564	1.07	46	42.7	2254	0.44	86	49.5	2300	0.03
7	6.3	646	1.10	47	43.2	2260	0.42	87	49.6	2300	0.03
8	7.4	728	1.13	48	43.6	2265	0.40	88	49.6	2300	0.03
9	8.5	811	1.15	49	44.0	2269	0.37	89	49.6	2300	0.03
10	9.7	892	1.17	50	44.4	2273	0.35	90	49.7	2300	0.02
11	10.8	973	1.18	51	44.7	2276	0.33	91	49.7	2300	0.02
12	12.0	1052	1.19	52	45.1	2279	0.31	92	49.7	2300	0.02
13	13.2	1129	1.19	53	45.4	2281	0.30	93	49.7	2300	0.02
14	14.4	1203	1.20	54	45.7	2284	0.28	94	49.7	2300	0.02
15	15.6	1276	1.19	55	45.9	2286	0.26	95	49.8	2300	0.02
16	16.8	1346	1.19	56	46.2	2288	0.25	96	49.8	2300	0.02
17	18.0	1413	1.18	57	46.5	2289	0.23	97	49.8	2300	0.01
18	19.2	1477	1.17	58	46.7	2291	0.22	98	49.8	2300	0.01
19	20.3	1538	1.16	59	46.9	2292	0.20	99	49.8	2300	0.01
20	21.5	1596	1.14	60	47.1	2293	0.19	100	49.8	2300	0.01
21	22.6	1652	1.12	61	47.3	2294	0.18	101	49.8	2300	0.01
22	23.7	1704	1.10	62	47.5	2295	0.17	102	49.9	2300	0.01
23	24.9	1753	1.08	63	47.6	2295	0.16	103	49.9	2300	0.01
24	25.9	1799	1.06	64	47.8	2296	0.15	104	49.9	2300	0.01
25	27.0	1842	1.04	65	48.0	2296	0.14	105	49.9	2300	0.01
26	28.0	1883	1.01	66	48.1	2297	0.13	106	49.9	2300	0.01
27	29.0	1920	0.98	67	48.2	2297	0.12	107	49.9	2300	0.01
28	30.0	1955	0.96	68	48.3	2298	0.11	108	49.9	2300	0.01
29	31.0	1987	0.93	69	48.5	2298	0.11	109	49.9	2300	0.01
30	31.9	2017	0.90	70	48.6	2298	0.10	110	49.9	2300	0.01
31	32.8	2044	0.87	71	48.7	2298	0.09	111	49.9	2300	0.01
32	33.7	2070	0.84	72	48.7	2299	0.09	112	49.9	2300	0.00
33	34.5	2093	0.81	73	48.8	2299	0.08	113	49.9	2300	0.00
34	35.3	2114	0.78	74	48.9	2299	0.07	114	49.9	2300	0.00
35	36.1	2133	0.75	75	49.0	2299	0.07	115	49.9	2300	0.00
36	36.9	2151	0.72	76	49.1	2299	0.06	116	49.9	2300	0.00
37	37.6	2166	0.69	77	49.1	2299	0.06	117	50.0	2300	0.00
38	38.3	2181	0.66	78	49.2	2299	0.06				
39	38.9	2194	0.63	79	49.2	2299	0.05				
40	39.5	2206	0.60	80	49.3	2300	0.05				

Diameter Growth curve: Diameter growth curved were draw with the help of the growth table placing annual diameter in Y-axis and time series in X-axis.Observation of growth trend in the graph was also another supportive method for ∂D_{max} determination. In some cases discussion also were made with the help of this greaph to the experts.



Computation of Age_{max}: Maximum age of the tree was computed with the help of the table. In the table this tree reached its maximum diameter and maximum height at the year 117 and then after there is no more growth, therefore this year is choose as the maximum age .

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Appendix-J:

Computation of ∂D_{max} , Age_{max} and tree growth table

Illustred example= *Anogeissus latifolius*

Major Problems:

- Preparation of diameter growth table
- Computation ∂D_{max}
- Computation Age_{max}

Known values:

- D_{max} = 90cm {collected from different sources described in 4.2.2.1 (a)}
- H_{max} = 2500cm {from different sources described in 4.2.2.1 (a)}
- 15^{th} years growth information , dbh =15 cm and Height = 9 m

(Jackson,1994, p392)

Supposed value: Initial dbh of the tree =1cm (dbh at the end of the year 1)

Supportive formulas: same as appendix I

Computation process:

Steps	Process	Ilustration
Step 1	Choose approximate value of ∂D_{max}	∂D_{max} =1.5cm (after many trails)
Step 2	Compute G value using formula-1.	G = 5*2500*1/(90)=208.3
Step 3	Compute b_2 and b_3 using formula 2 and 3	$b_2 = \frac{2(2500-137)}{90} = 52.5$ & $b_3 = \frac{(2300-137)}{50*50} = 0.29$

Step 4: Make diameter growth table formate

Year	Diameter	Height	Diameter increment
1	1.0	189	0.48
2	1.48	214	0.61
3			
15	14.7	844	1.24

At the year 15^{th}, computed diameter and height were matched with observed diameter and height for that year, therefore ∂D_{max} =1.5cm were fixed for this species and the long periods growth table were prepaed (see table below).

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Computed growth table for *Anogeissus latifolius*

Year	Diam	Ht	Dia. Incre.	Year	Diam	Ht	Dia. Incre.	Year	Diam	Ht	Dia. Incre.
1	1.0	189	0.48	72	73.8	2423	0.57	143	89.1	2500	0.04
2	1.5	214	0.61	73	74.4	2429	0.55	144	89.1	2500	0.04
3	2.1	246	0.73	74	74.9	2434	0.54	145	89.1	2500	0.04
4	2.8	283	0.83	75	75.5	2438	0.52	146	89.2	2500	0.03
5	3.6	325	0.91	76	76.0	2443	0.50	147	89.2	2500	0.03
6	4.6	370	0.97	77	76.5	2447	0.49	148	89.2	2500	0.03
7	5.5	418	1.03	78	77.0	2450	0.47	149	89.3	2500	0.03
8	6.6	469	1.07	79	77.4	2454	0.46	150	89.3	2500	0.03
9	7.6	521	1.11	80	77.9	2457	0.44	151	89.3	2500	0.03
10	8.7	574	1.14	81	78.3	2460	0.43	152	89.4	2500	0.03
11	9.9	627	1.17	82	78.8	2463	0.42	153	89.4	2500	0.03
12	11.0	681	1.19	83	79.2	2466	0.40	154	89.4	2500	0.02
13	12.2	736	1.21	84	79.6	2468	0.39	155	89.4	2500	0.02
14	13.4	790	1.22	85	80.0	2471	0.38	156	89.5	2500	0.02
15	14.7	844	1.24	86	80.3	2473	0.36	157	89.5	2500	0.02
16	15.9	898	1.25	87	80.7	2475	0.35	158	89.5	2500	0.02
17	17.1	952	1.26	88	81.1	2477	0.34	159	89.5	2500	0.02
18	18.4	1005	1.27	89	81.4	2478	0.33	160	89.5	2500	0.02
19	19.7	1057	1.27	90	81.7	2480	0.32	161	89.6	2500	0.02
20	20.9	1109	1.28	91	82.0	2482	0.30	162	89.6	2500	0.02
21	22.2	1160	1.28	92	82.3	2483	0.29	163	89.6	2500	0.02
22	23.5	1210	1.28	93	82.6	2484	0.28	164	89.6	2500	0.02
23	24.8	1260	1.28	94	82.9	2485	0.27	165	89.6	2500	0.02
24	26.1	1308	1.28	95	83.2	2486	0.26	166	89.6	2500	0.01
25	27.4	1355	1.28	96	83.5	2488	0.25	167	89.7	2500	0.01
26	28.6	1402	1.28	97	83.7	2488	0.24	168	89.7	2500	0.01
27	29.9	1447	1.28	98	84.0	2489	0.24	169	89.7	2500	0.01
28	31.2	1491	1.27	99	84.2	2490	0.23	170	89.7	2500	0.01
29	32.5	1535	1.27	100	84.4	2491	0.22	171	89.7	2500	0.01
30	33.7	1577	1.26	101	84.6	2492	0.21	172	89.7	2500	0.01
31	35.0	1617	1.25	102	84.9	2492	0.20	173	89.7	2500	0.01
32	36.3	1657	1.24	103	85.1	2493	0.20	174	89.7	2500	0.01
33	37.5	1696	1.23	104	85.2	2493	0.19	175	89.8	2500	0.01
34	38.7	1733	1.22	105	85.4	2494	0.18	176	89.8	2500	0.01
35	40.0	1769	1.21	106	85.6	2494	0.17	177	89.8	2500	0.01
36	41.2	1804	1.20	107	85.8	2495	0.17	178	89.8	2500	0.01
37	42.4	1838	1.19	108	86.0	2495	0.16	179	89.8	2500	0.01
38	43.6	1871	1.18	109	86.1	2496	0.15	180	89.8	2500	0.01
39	44.7	1902	1.16	110	86.3	2496	0.15	181	89.8	2500	0.01
40	45.9	1933	1.15	111	86.4	2496	0.14	182	89.8	2500	0.01
41	47.0	1962	1.13	112	86.6	2497	0.14	183	89.8	2500	0.01
42	48.2	1990	1.12	113	86.7	2497	0.13	184	89.8	2500	0.01
43	49.3	2017	1.10	114	86.8	2497	0.13	185	89.8	2500	0.01
44	50.4	2042	1.09	115	87.0	2497	0.12	186	89.8	2500	0.01
45	51.5	2067	1.07	116	87.1	2498	0.12	187	89.9	2500	0.01
46	52.5	2091	1.05	117	87.2	2498	0.11	188	89.9	2500	0.01
47	53.6	2113	1.03	118	87.3	2498	0.11	189	89.9	2500	0.01
48	54.6	2135	1.02	119	87.4	2498	0.10	190	89.9	2500	0.01
49	55.6	2156	1.00	120	87.5	2498	0.10	191	89.9	2500	0.01
50	56.6	2175	0.98	121	87.6	2498	0.10	192	89.9	2500	0.00
51	57.6	2194	0.96	122	87.7	2498	0.09	193	89.9	2500	0.00
52	58.6	2212	0.94	123	87.8	2499	0.09	194	89.9	2500	0.00
53	59.5	2229	0.92	124	87.9	2499	0.09	195	89.9	2500	0.00
54	60.4	2245	0.90	125	88.0	2499	0.08	196	89.9	2500	0.00
55	61.4	2261	0.88	126	88.1	2499	0.08	197	89.9	2500	0.00
56	62.2	2275	0.86	127	88.2	2499	0.08	198	89.9	2500	0.00
57	63.1	2289	0.85	128	88.2	2499	0.07	199	89.9	2500	0.00
58	63.9	2302	0.83	129	88.3	2499	0.07	200	89.9	2500	0.00
59	64.8	2314	0.81	130	88.4	2499	0.07	201	89.9	2500	0.00
60	65.6	2326	0.79	131	88.4	2499	0.06	202	89.9	2500	0.00
61	66.4	2337	0.77	132	88.5	2499	0.06	203	89.9	2500	0.00
62	67.1	2347	0.75	133	88.6	2499	0.06	204	89.9	2500	0.00
63	67.9	2357	0.73	134	88.6	2499	0.06	205	89.9	2500	0.00
64	68.6	2367	0.71	135	88.7	2499	0.05	206	89.9	2500	0.00
65	69.3	2375	0.69	136	88.7	2500	0.05	207	89.9	2500	0.00
66	70.0	2384	0.67	137	88.8	2500	0.05	208	89.9	2500	0.00
67	70.7	2391	0.66	138	88.8	2500	0.05	209	89.9	2500	0.00
68	71.4	2399	0.64	139	88.9	2500	0.05	210	89.9	2500	0.00
69	72.0	2405	0.62	140	88.9	2500	0.04	211	89.9	2500	0.00
70	72.6	2412	0.60	141	89.0	2500	0.04	212	89.9	2500	0.00
71	73.2	2418	0.59	142	89.0	2500	0.04	213	90.0	2500	0.00

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Computation of Age_{max}:

Guiding formula for computation of Age_{max}
= 2/3 of Dbh of its D_{max} is reached at haft of the maximum age Age_{max} (Botkin, 1993)

Step 1: calculation of 2/3 of D_{max} =2/3 *90 =60cm

Step 2: Look at the year that contains the dbh=60 in the growth table (recently prepared).

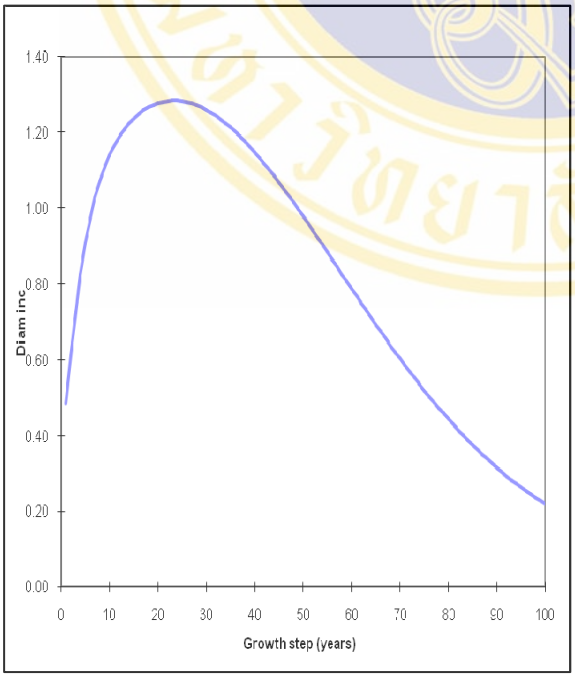
Year 54 contains 60.4 cm dbh in the table.

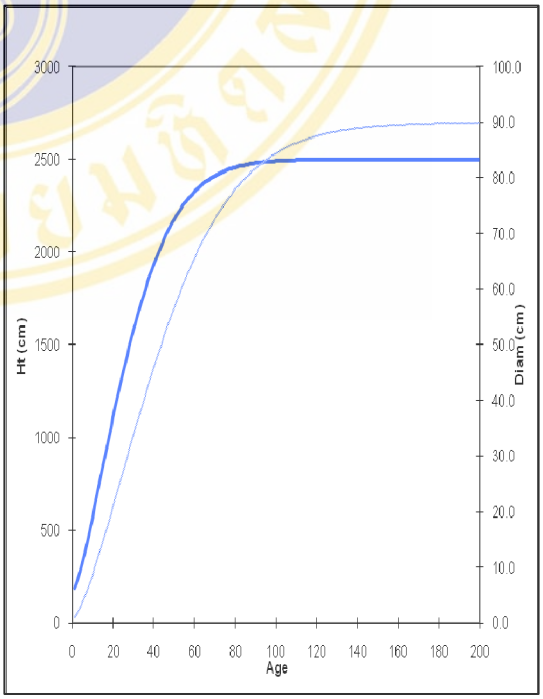
Step 3: Double the age of step 2.

Because 2/3 of Dmax reached at half age, therefore full age is just double. Doubling 54 means 108. Thefore maximum age for this species is 108 year.

Computation of diameter and height growth curves:

Graph-1 shows yearly diameter growth. It is showing increment is peak at 25 -35 year. Graph-2 shows status of the diameter and height with respect to time. For all the species these two types of two graphs were drawn. Both graphs are important to know the growth pattern of the particular species. Discuss also necessary with experts to know the whether growth trend of graph is matching with rea situation or not.





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Appendix-K

Computed value of G, b_1 and b_2 for all the the species

SN	Species	G	B_1	B_2		SN	Species	G	B_1	B_2
1	*Acacia catechu*	322	86.52	0.865		29	*Duabanga grandiflora*	75	71.58	0.45
2	*Actinodaphne angusifolia*	53	65.02	0.72		30	*Ehretia wallichiana*	60	69.04	1.38
3	*Adina cordifolia*	72	30.57	0.07		31	*Ficus beghalensis*	90	57.26	0.29
4	*Aegle marmelos*	65	58.15	0.73		32	*Ficus benjamina*	63	90.52	0.91
5	*Albizia lebbeck*	252	66.52	0.67		33	*Garuga pinnata*	344	93.20	0.85
6	*Anogeissus latifolius*	208	52.51	0.29		34	*Glochidion velutinum*	50	60.58	0.67
7	*Anthocephalus chinensis*	700	74.52	0.75		35	*Grewia optiva*	176	82.52	0.83
8	*Aporusa octandra*	68	83.15	1.04		36	*Gmelina arborea*	107	81.80	0.58
9	*Bauhinia purpurea*	170	104.20	1.74		37	*Holarrhena pubescens*	100	57.53	0.96
10	*Bauhinia variegata*	120	72.17	1.03		38	*Hymenodictyon excelsum*	51	47.51	0.34
11	*Bischofia Javanica*	129	95.03	1.36		39	*Largerstroemia parviflora*	208	44.05	0.17
12	*Bombax ceiba*	267	42.92	0.12		40	*Lannea coromandelica*	125	67.51	0.48
13	*Bridelia retusa*	100	82.88	2.59		41	*Litsea monopetala*	233	56.13	0.62
14	*Buchanania latifolia*	80	37.26	0.19		42	*Mallotus philippensis*	102	123.91	2.82
15	*Butea monosperma*	43	38.94	0.28		43	*Myrsine semiserrata*	107	100.58	1.12
16	*Careya arborea*	38	68.15	0.85		44	*Phyllanthus emblica*	252	133.04	2.66
17	*Casearia graveoles*	20	70.87	1.18		45	*Pterocarpus marsupium*	124	79.01	0.53
18	*Cassia fistula*	150	45.43	0.38		46	*Randia dumetorum*	19	88.40	2.95
19	*Cassine glauca*	55	51.58	0.32		47	*Schleichera oleosa*	50	63.01	0.42
20	*Carpesium nepalense*	90	109.04	2.18		48	*Semecarpus anacardium*	67	57.53	0.96
21	*Cedrela toona*	270	51.26	0.26		49	*Shorea robusta*	319	42.90	0.09
22	*Cleistocalyx operculatus*	140	75.43	0.63		50	*Syzygium cumini*	240	74.52	0.75
23	*Cornus oblonga*	100	93.15	1.16		51	*Terminalia alata*	83	31.81	0.09
24	*Dalbergia latifolia*	187	51.51	0.17		52	*Terminalia bellirica*	248	73.46	0.38
25	*Dalbergia sissoo*	500	76.35	0.51		53	*Terminalia chebula*	117	55.01	0.37
26	*Desmodium oojeinense*	63	59.08	0.37		54	*Trewia nudiflora*	180	72.17	1.03
27	*Dillenia pentagyna*	73	55.01	0.37		55	*Xeromphis utiginosa*	40	132.60	6.63
28	*Diospyros malabarica*	100	72.17	1.03						

Note :
Above three constants were computed by using following formulas seperatly for each species (calculation method also explained in Appendix-III)

- $G_{\partial \mathrm{Dmax}} \cong 5H_{\max}\left(\frac{\partial D_{\max}}{D_{\max}}\right).$
- $b_2 = \frac{2(H\max - 137)}{D\max}.$ and $b_3 = \frac{(H\ \max\ - 137\ )}{D^{\ 2}\ \max}$

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Appendix-L

Model predicted species for different successional stage

	Early successional stage (Year 20)	Mid successional stage (Year 50)	Late successional stage (Year 100)	Early climax stage (Year 350)	Climax stage (Year 500)
1	Dalbergia sissoo	Dalbergia sissoo	Shorea robusta	Shorea robusta	Shorea robusta
2	Shorea robusta	Cleistocalyx operculatus	Dalbergia latifolia	Terminalia alata	Largerstroemia parviflora
3	Dalbergia latifolia	Cedrela toona	Cedrela toona	Dalbergia latifolia	Adina cordifolia
4	Litsea monopetala	Dalbergia latifolia	Cleistocalyx operculatus	Adina cordifolia	Cedrela toona
5	Acacia catechu	Acacia catechu	Terminalia alata	Cedrela toona	Cleistocalyx operculatus
6	Terminalia bellirica	Litsea monopetala	Bombax ceiba	Bombax ceiba	Cassia fistula
7	Bauhinia purpurea	Syzygium cumini	Terminalia chebula	Largerstroemia parviflora	Litsea monopetala
8	Albizia lebbek	Cassia fistula	Adina cordifolia	Terminalia bellirica	Syzygium cumini
9	Cleistocalyx operculatus	Bauhinia purpurea	Cassia fistula	Cassia fistula	Dillenia pentagyna
10	Bombax ceiba	Shorea robusta	Litsea monopetala	Desmodium oojeinense	Terminalia bellirica
11	Largerstroemia parviflora	Terminalia bellirica	Diospyros malabarica	Litsea monopetala	Butea monosperma
12	Anthocephalus chinensis	Bombax ceiba	Bauhinia variegata	Cleistocalyx operculatus	Grewia optiva
13	Bauhinia variegata	Phyllanthus emblica	Cassine glauca	Bischofia Javanica	Bauhinia variegata
14	Phyllanthus emblica	Mallotus philippensis	Largerstroemia parviflora	Terminalia chebula	Aegle marmelos
15	Cassia fistula	Holarrhena pubescens	Carpesium nepalense	Bauhinia variegata	Myrsine semiserrata
16	Terminalia chebula	Butea monosperma	Butea monosperma	Butea monosperma	Diospyros malabarica
17	Terminalia alata	Randia dumetorum	Dillenia pentagyna	Trewia nudiflora	Cassine glauca
18	Aegle marmelos	Aegle marmelos	Garuga pinnata	Cassine glauca	Buchanania latifolia
19	Diospyros malabarica	Adina cordifolia	Pterocarpus marsupium	Dillenia pentagyna	Terminalia alata
20	Ficus beghalensis	Bauhinia variegata	Terminalia bellirica	Grewia optiva	Dalbergia latifolia
21	Adina cordifolia	Desmodium oojeinense	Phyllanthus emblica	Randia dumetorum	Bombax ceiba
22	Holarrhena pubescens	Dillenia pentagyna	Duabanga grandiflora	Buchanania latifolia	Desmodium oojeinense
23	Butea monosperma	Anogeissus latifolius	Dalbergia sissoo	Phyllanthus emblica	Bischofia Javanica
24	Dillenia pentagyna	Largerstroemia parviflora	Acacia catechu	Aegle marmelos	Terminalia chebula
25	Bischofia Javanica	Terminalia chebula	Syzygium cumini	Garuga pinnata	Trewia nudiflora
26	Trewia nudiflora	Terminalia alata	Bauhinia purpurea	Holarrhena pubescens	Randia dumetorum
27	Cassine glauca	Diospyros malabarica	Mallotus philippensis	Myrsine semiserrata	Phyllanthus emblica
28	Garuga pinnata	Cassine glauca	Holarrhena pubescens	Schleichera oleosa	Garuga pinnata
29	Anogeissus latifolius	Garuga pinnata	Randia dumetorum	Diospyros malabarica	Holarrhena pubescens
30	Randia dumetorum	Carpesium nepalense	Aegle marmelos	Carpesium nepalense	Schleichera oleosa
31	Actinodaphne angusifolia	Myrsine semiserrata	Desmodium oojeinense	Pterocarpus marsupium	Carpesium nepalense
32	Aporusa octandra	Pterocarpus marsupium	Anogeissus latifolius	Duabanga grandiflora	Pterocarpus marsupium
33	Bridelia retusa	Albizia lebbek	Myrsine semiserrata	Dalbergia sissoo	Duabanga grandiflora
34	Buchanania latifolia	Anthocephalus chinensis	Albizia lebbek	Acacia catechu	Dalbergia sissoo
35	Careya arborea	Ficus beghalensis	Anthocephalus chinensis	Syzygium cumini	Acacia catechu
36	Casearia graveoles	Bischofia Javanica	Ficus beghalensis	Bauhinia purpurea	Bauhinia purpurea
37	Carpesium nepalense	Trewia nudiflora	Bischofia Javanica	Mallotus philippensis	Mallotus philippensis
38	Cedrela toona	Actinodaphne angusifolia	Trewia nudiflora	Anogeissus latifolius	Anogeissus latifolius
39	Cornus oblonga	Aporusa octandra	Actinodaphne angusifolia	Albizia lebbek	Albizia lebbek
40	Desmodium oojeinense	Bridelia retusa	Aporusa octandra	Anthocephalus chinensis	Anthocephalus chinensis
41	Duabanga grandiflora	Buchanania latifolia	Bridelia retusa	Ficus beghalensis	Ficus beghalensis
42	Ehretia wallichiana	Careya arborea	Buchanania latifolia	Actinodaphne angusifolia	Actinodaphne angusifolia
43	Ficus benjamina	Casearia graveoles	Careya arborea	Aporusa octandra	Aporusa octandra
44	Glochidion velutinum	Cornus oblonga	Casearia graveoles	Bridelia retusa	Bridelia retusa
45	Grewia optiva	Duabanga grandiflora	Cornus oblonga	Careya arborea	Careya arborea
46	Gmelina arborea	Ehretia wallichiana	Ehretia wallichiana	Casearia graveoles	Casearia graveoles
47	Hymenodictyon excelsum	Ficus benjamina	Ficus benjamina	Cornus oblonga	Cornus oblonga
48	Lannea coromandelica	Glochidion velutinum	Glochidion velutinum	Ehretia wallichiana	Ehretia wallichiana
49	Mallotus philippensis	Grewia optiva	Grewia optiva	Ficus benjamina	Ficus benjamina
50	Myrsine semiserrata	Gmelina arborea	Gmelina arborea	Glochidion velutinum	Glochidion velutinum
51	Pterocarpus marsupium	Hymenodictyon excelsum	Hymenodictyon excelsum	Gmelina arborea	Gmelina arborea
52	Schleichera oleosa	Lannea coromandelica	Lannea coromandelica	Hymenodictyon excelsum	Hymenodictyon excelsum
53	Semecarpus anacardium	Schleichera oleosa	Schleichera oleosa	Lannea coromandelica	Lannea coromandelica
54	Syzygium cumini	Semecarpus anacardium	Semecarpus anacardium	Semecarpus anacardium	Semecarpus anacardium
55	Xeromphis utiginosa	Xeromphis utiginosa	Xeromphis utiginosa	Xeromphis utiginosa	Xeromphis utiginosa

Note:

- Species are ranked most dominant to descresing order in each stage (column).
- Light shadow is used for most dominat species for that stage.
- Dark shadow is used for non predicted species for that satage.

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Appendix-M

People consulted[2] and involved in the field work

I. Consulted CNP official in Field

		Position	Degree
1	Mr. Meg Bahadur Pandey	Chief conservation Officer	M.S.
2	Mr. Kamal Janga Kuwar	Conservation Officer	B.Sc. Forestry
3	Mr. Ana Nath Baral	Conservation Officer	B.Sc. Forestry
4	Mr. Karun Pandit	Conservation Officer	M.Sc. Forestry
5	Mr. Sugan Maharjan	Ranger	B.Sc. Forestry

II. Local people involved in field work

		Address	Age	Education
1	Mr. Binod Shereshtha	Jagatpur VDC, Chitawan	22	Intermediate
2	Mr. Dipak B.Ka.	Jagatpur VDC, Chitawan	27	Literate
3	Mr. Bhim Bahadur Gurung	Jagatpur VDC, Chitawan	30	High School
4	Mr. Bhallu Chaudhari	Jagatpur VDC, Chitawan	72	-
5	Mr. Dukhi Ram Chaudhari	Jagatpur VDC, Chitawan	66	-
6	Mr. Bhagwan Tharu	Jagatpur VDC, Chitawan	65	-
7	Mr. Ram Dase Tharu	Jagatpur VDC, Chitawan	46	Literate
8	Mr. Prem Sharma	Gitanagar VDC, Chitawan	41	Intermediate
9	Mr. Ramji Devkota	Gitanagar VDC, Chitawan	35	High School
10	Mr. Kallu Nepali	Gitanagar VDC, Chitawan	21	Intermediate
11	Mr. Sudhir Shreshtha	Gitanagar VDC, Chitawan	20	High School
12	Mr. Dasi Ram Chaudhari	Gitanagar VDC, Chitawan	69	-
13	Mr. Kashi Nath Lamichhane	Gitanagar VDC, Chitawan	52	Literate
14	Mr. Budhai Chaudhari	Gitanagar VDC, Chitawan	70	Literate
15	Mr. Lattu Chaudhari	Gitanagar VDC, Chitawan	64	-

III. Research assisstant involved in field work

	Name	Education	Remarks
1	Mr. Khagendra Raj Baral	B.Sc. Forestry	16 yrs experience
2	Mr. Saket Sharma	B.Sc. (Biology)	4 Year experience
3	Mr. Pravin Gautam	Intermediate	-

[2] Local community peoples involved in the discussion out side the CNP are not included in this name lists. Similary, Forest Guards and other many employ of the CNP especially Kasar based and Debnagar post based were participated in the discussion and partly were involved in field measurement but their long list in not included in this list.

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Appendix-N

Bibiography of the consulted Experts

Dr. Rajendra Gyawali

Position: Lecturer

Organization and department: Tribhuwan University, Central Deprtment of Botany

Degree: B.Sc. Botany, M.Sc. Botany, Ph.D. Plant Phisiology

Type of organization: Academic

Experience in Acdemic Field: 5 Years

Publication: Four research articles in pair reviewed journal (As a main researcher)

Mr. Krishna Acharya

Position: Under Secreatary, Senior Research Officer

Degree: B.Sc. Forestry, M.Sc. Forestry

Organization: Department of Forest Research and Survey, Forest Research Division, Government of Nepal

Type of organization: Goverment

Experience in Forestry Field: 17 Years

Publication: Three research articles in pair reviewed journal (As a main researcher)

Mr. Ram Chadra Nepal

Position: Senior Conservation Officer

Degree: B.Sc. Forestry, M.Sc. Natural Resource Management

Organization: National Trust for Nature Conservation

Office: Chitawan National Park

Type of organization: Non Governmental Organization (NGO)

Experience in Conservation field: 14 Years

Publication: One research articles in pair reviewed journal (As a main researcher)

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BIOGRAPHY

NAME	Mr. Dipak Jnawali
DATE OF BIRTH	December 5th, 1968
PLACE OF BIRTH	Daugha-7, Gulmi, Nepal
INSTITUTE ATTENDED	Tribhuvan University, Trichandra Campus, Kathmandu (1989- 1991), Bachelor of Science (General Science) Tribhuvan University, Institute of Forestry, Pokhara Campus (1992- 1995), Bachelor of Science (General Forestry) Mahidol University (2006- 2008), Master of Science (Natural Resource Management)
FELLOWSHIP STUDY GRANT	Thailand- Colombo Plan Long-Term Fellowship Programme for the Academic year 2006-2008 (Jointly offer by Thailand International Cooperation Agency and Colombo Plan Secretariat)
POSITION AND OFFICE	Forest Officer, Ministry of Forest and Soil Conservation, Singhadurbar, Kathmandu, Nepal
HOME ADDRESS	Gajehada -8, Babhani, District Kapilbastu, Zone Lumbini, Nepal E-mail: dipakjnawali@gmail.com

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