

**Species Distribution and Ecological Niche Modelling of
Alnus Species in Nepal**

**A Dissertation Submitted for Partial Fulfillment of the Requirements for the Master's
Degree in Science, Central Department of Botany, Tribhuvan University**



Submitted by

Santosh Kumar Rana

Plant Systematics and Biodiversity Unit

Exam Roll No.: 18214

T.U. Regd. No.: 5-2-37-440-2007

Central Department of Botany

Tribhuvan University

Kirtipur, Kathmandu, Nepal

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RECOMMENDATION

It is hereby recommended that **Mr. Santosh Kumar Rana**, a M.Sc. Botany final year student at Tribhuvan University, Institute of Science and Technology, Kirtipur, Kathmandu has carried out research work entitled “**Species Distribution and Ecological Niche Modelling of Alnus Species in Nepal**” under our joint supervision. This entire work is based on the herbarium specimen and database of different herbaria and brings out useful findings in the field of biodiversity and biogeography. The work has not been submitted for any other academic degree.

This dissertation has been recommended for acceptance as a partial fulfillment of the requirement of Master’s Degree in Botany at Institute of Science and Technology, Tribhuvan University.



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Ref No:


LETTER OF APPROVAL

KIRTIPUR, KATHMANDU
NEPAL

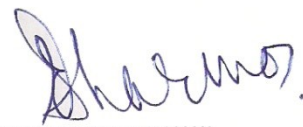
The M.Sc. dissertation entitled “Species Distribution and Ecological Niche Modelling of *Alnus* Species in Nepal” submitted by Mr. Santosh Kumar Rana has been accepted for the partial fulfillment of his Master’s Degree in Botany (Plant Systematics and Biodiversity).

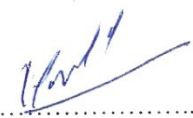
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Disclaimer

This dissertation describes research work undertaken as a partial fulfillment of the requirement of Master's Degree in Botany at Institute of Science and Technology, Tribhuvan University. All views and opinions expressed therein remain the sole responsibility of the author and do not necessarily represent those of the other institute. This material has not been submitted, either in whole or in part, for a degree at this or any other institution.

14th December, 2014

Santosh Kumar Rana

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14th December, 2014

Santosh K. Rana

ABBREVIATIONS AND ACRONYMS

Abb.	Abbreviation
Abr. Ed.	Abridged Edition
Ann. Check. Fl. Pl. Nepal	Annotated Checklist of Flowering Plants of Nepal.
a.s.l	above sea level
ca.	approximate
cat.	Category
CO ₂	Carbondioxide
CRP	CGIAR Research Programme
e.g.	<i>exempli gratia</i> or 'for example'
ed.	Edition
Eng.	English
et al.	<i>et alia</i> or 'and others'
Fl.	Flowering
Fl. Siml.	Flora Simlensis
Fr.	Fruiting
Gard. Dict.	Gardening Dictionary
Gen. Pl. Suppl.	Genera Plantarum Supplimentary
i.e.	<i>id est</i> : that is
ICIMOD	International Centre for Integrated Mountain Development
ICRAF	International Centre for Research in Agroforestry (World Agroforestry Centre)
IPCC	Intergovernmental Panel on Climate Change
KATH	National Herbarium and Plant Laboratories, Kathmandu
NBS	Nepal Biodiversity Strategy
Nep.	Nepali
Prodr. Fl. Nepal.	Prodromus Florae Nepalensis
sp.	species (singular = sp. and plural = spp.)
TU	Tribhuvan University
TUCH	Tribhuvan University Central Herbarium
VDC	Village Development Committee
WCE	Western Central Eastern

ABSTRACT

Alnus (Alder) is important taxa in agroforestry system because of its ability to fix atmospheric nitrogen. Himalayan alder species such as *A. nepalensis* and *A. nitida* are proven to be very useful in traditional as well as contemporary agroforestry practice. This implies to the importance of studying biogeographical distribution of these species to identify the climatical suitable zone. The climatic suitable zone of two species of genus *Alnus* were modelled using a subset of least correlated bioclimatic variables for current condition (1950-2000), topographic variables (DEM derived) and Landuse Landcover (LULC) data.

MaxEnt method was used to predict the suitability of *Alnus* species based on 79 randomly distributed points (67 of *A. nepalensis* and 12 of *A. nitida*). Four models were produced for each species in a stepwise combination of variables. The best model was chosen against random model based on AUC value of Maxent using ANOVA and t-test. The model selected for further analysis comprises mean AUC value of 0.889 for *A. nepalensis* and 0.946 for *A. nitida*. The environmental variables that best explained the current distribution of the species were identified and used to project the climatically suitable niche into the future, and identify the suitable areas for mixed agroforestry. The most favourable conditions for *A. nepalensis* were located in Central Nepal in the moist North-West facing slope and degraded hilly region above Siwalik range from East to West; whereas, that of *A. nitida* was located in drier South-East facing Western Himalaya along river valley of Nepal. The model revealed that the Dhaulagiri Range and Annapurna range separates habitat of two *Alnus* species in Nepal. The rising mountain slopes in the northern region even acts as barriers for *A. nepalensis* distribution. Presence of rough terrain of high Himalaya fragmented the habitat of *A. nitida*. The major contribution factor for distribution in Nepal was found to be precipitation of warmest quarter and precipitation of drier quarter for *A. nepalensis* and *A. nitida* respectively.

The model revealed that climatically suitable area occupied for *A. nepalensis* is ca. 47610 km² and *A. nitida* ca. 14690 km² in current scenario. While in the future projection of SRES-A1B scenario for 2050, *A. nepalensis* was found to decrease its suitability area by ca. 16720 km² whereas that of *A. nitida* decreases by ca. 3405 km². Prediction for SRES-A1B scenario 2050 shows significant loss in area of *Alnus* species (15.74% for *A. nepalensis* and 5.38% for *A. nitida*) as compared to the suitable area gained (7.32% for *A. nepalensis* and 0.67% for *A. nitida*). The unchanged stable areas in Hilly region are probable sites for the introducing these species in the agroforestry system.

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CHAPTER 1

INTRODUCTION

1.1 Background

Why species are found in certain geographical areas and how they got there, has fascinated biogeographers and ecologists for more than two centuries (Darwin, 1859; Grinnell, 1917; Connell, 1961). As a basic unit of investigation for such questions, researchers often address the geographical range of a species, which is characterized by the complex interplay of a species characteristics and its environment (Brown *et al.*, 1996). The geographical range of a species may be dynamic and can change within relatively short timescales, e.g. summer and winter ranges or breeding and non-breeding ranges of mobile species like most animals. For non-mobile species like plants, geographical ranges may only respond dynamically over longer time spans, since individuals often stay in the same place during their whole life cycle and dispersion is bound to reproduction, although biotic and abiotic factors may enhance their dispersal (Nathan and Muller-Landau, 2000).

Contemporary climate change is assumed to rapidly alter large-scale plant species distributions (Parmesan and Yohe, 2003; Thomas, 2010) and species have to adjust their ranges at a rate equal to the shifting climate in order to track suitable environmental conditions (Parmesan *et al.*, 1999). However, if a species is highly limited in its ability to migrate, then it must either rapidly adapt to the new environmental conditions in their current habitat (Pearman *et al.*, 2008), or it will go locally extinct (Channell and Lomolino, 2000).

Ecological niche is a term for the position of a species within an ecosystem, describing both the range of conditions necessary for persistence of the species, and its ecological role in the ecosystem. Ecological niche represents a very basic and fundamental ecological concept.

1.1.1 Formulation of the niche concept

Joseph Grinnell (1917, 1924) used the term ‘niche’ to describe the environmental conditions within which a species can survive and reproduce; these could include abiotic factors, such as temperature or rainfall, or interactions with other species (Grinnell, 1924; Vandermeer, 1972). Charles Elton (1927) found a species niche as its place or role within the ecological community, placing less emphasis on the abiotic conditions and more on relationships with

other species (Vandermeer, 1972) and the impact that species have on the environment (Leibold, 1995; Chase and Leibold, 2003). Niche theory was first properly formalized by G. E. Hutchinson (1957). He described a species fundamental niche as a space in an n-dimensional hypervolume defined by numerous (abiotic) environmental axes. Hutchinson's (1957) fundamental niche describes the environmental conditions within which a species could survive and reproduce in the absence of interactions with other species. The realized niche describes the environmental conditions within which a species actually lives, taking into account interactions with other species. Species distribution models deal with Grinnellian or Hutchinsonian fundamental niches, rather than Eltonian niches (Peterson, 2006). In recent years, a number of important developments have been made to niche theory. They are interlinked with *Dispersal limitation* (Pulliam, 2000), *Source-sink dynamics* (Pulliam, 1988) or *Neutral theory* (Hubbell, 1997).

1.1.2 Using niche theory to model the distributions of species

The manner where a biological taxon is spatially arranged is called as species distribution. Species distribution can be potentially predicted based on the pattern of biodiversity at spatial scales. Based on the factors of dispersal disturbance, resource limiting climate and other species distribution, prediction of species distribution can create a bio-climate range, or bio-climate envelope.

Species distribution models (SDMs) can be defined as associative models relating occurrence or abundance data at known locations of individual species (distribution data) to information on the environmental characteristics of those locations (Elith and Leathwick, 2009; Guisan and Thuiller, 2005; Hirzel and Le Lay, 2008). The species distribution model can predict the potential spatial distribution of a phenomenon by relating sites of known occurrence and absence with predictor variables. The common application of this model is to predict species ranges with physio-geographical, biological and climatic data as predictors.

The use of species distribution models has increased rapidly in the last two decades and recent years have seen the development of several new modelling techniques (Phillips *et al.*, 2006). Although species distribution models are based on niche theory, the theory is often lost in the statistics. Since distribution models are correlative, it may be possible to develop a seemingly accurate model for a species without capturing causal relationships between species occurrence and the environment (Hirzel and Le Lay, 2008). These concerns have

prompted several authors to call for a greater consideration of ecological theory when developing distribution models (Guisan and Thuiller, 2005; Soberón and Peterson, 2005; Austin, 2007).

A crucial consideration that is often overlooked is exactly what component of a species niche is being modelled (Soberon and Peterson, 2005; Soberon, 2007). Soberon and Peterson (2005) distinguish three broad categories of factors that determine the distributions of species: abiotic environmental factors, biotic factors concerning interactions among species, and factors that affect the ability of species to disperse to different areas. Areas that meet the abiotic conditions required by the species are part of the fundamental niche. Areas that meet aforementioned and also contain an appropriate combination of interacting species make up the realized niche. Finally, those parts of the realized niche that can be accessed by the species in question constitute the actual distribution (Soberon and Peterson, 2005).

Several authors have argued that distribution models capture the realized niche, even if they only use abiotic variables in the models, because data on species occurrence used to build models describe actual (realized) distributions (Guisan and Zimmermann, 2000; Pearson and Dawson, 2003; Araujo and Guisan, 2006). On the other hand, Soberon and Peterson (2005) argue that, unless variables describing biotic interactions or dispersal limitation are included as explanatory variables, distribution models generally capture the fundamental niche. An exception to this rule occurs when biotic variables covary with abiotic variables, in which case the model may more closely approximate the realized distribution (Soberon and Peterson, 2005).

Species distribution modelling is emerging tool for predicting species niches (Ranjitkar *et al.*, 2014a). They are being used extensively in the field of biogeography, ecology, evolutionary biology, plant systematic, phylogeny to understand aspects of biogeography, identify sites for reintroductions, forecast effects of environmental change, etc. (Peterson, 2006). Moreover, they are used in the conservation of species, modelling species richness patterns, predicting future distributions, predicting the extent of species invasions, addressing the ecological and evolutionary questions.

1.1.3 Dispersal, neutrality and spatial autocorrelation

As we have seen earlier, dispersal limitation can play an important role in shaping species distributions, causing species to be absent from areas that would otherwise be suitable (Pulliam, 2000). Similarly, the existence of source-sink dynamics means that a species can be maintained outside suitable habitat by continual dispersal (Pulliam, 2000). These processes will lead to spatial patterns in distributions (Segurado *et al.*, 2006; Bahn *et al.*, 2008), whereby sites close to areas occupied by a species are more likely to be occupied than more distant sites; this phenomenon is known as spatial autocorrelation, specifically positive spatial autocorrelation (Legendre, 1993).

1.1.4 Concept of ecological niche model

The mathematical concept of ecological niche is a complex process involving large number parameters (climatic, topographical, edaphic and associations) and adequate location data collected from the field. Modelling using various optimization technique concepts is practiced to spatially determine ecological niche and it is termed as Ecological Niche Modelling (Hutchinson, 1957). A Model predicts the potential distribution of species, emphasizing the need for reliable methods to evaluate the accuracy of their predictions (Guisan and Zimmermann, 2000).

1.1.5 Modelling of species ecological niches

Ecological niche modelling studies have three basic components: a data set describing the occurrence of the species of interest and a data set of putative explanatory variables; a mathematical model that relates the occurrence data to the explanatory variables and an assessment of the utility of the model developed in terms of a validation exercise or an assessment of model robustness. Numerous approaches have been used to predict potential distributions based on models of species' ecological niche.

1.1.6 Future prediction

The use of ecological niche modelling in the emerging field of climate change ecology has been heavily criticized both on its fundamental premises and on the uncertainties underlying ecological forecasts (Araújo and Guisan, 2006). It is believed that the more severe impacts of

climate change will be a consequence of interaction with other threats (Thomas *et al.*, 2004). Unfortunately, climate change is unavoidable (Thomas *et al.*, 2004), but by minimizing greenhouse gas emissions, and increasing carbon sequestration, it may be possible to achieve the minimum expected climate change, and prevent a large number of terrestrial species from going extinct (Thomas *et al.*, 2004).

1.1.7 Future climatic scenarios of Intergovernmental Panel on Climate Change (IPCC)

The future prediction of *Alnus* species was carried out by using the Maxent model. The best climate change projection for the entire globe are made by Intergovernmental Panel on Climate Change (IPCC). The IPCC scenarios are globally recognized and thought to be more realistic. Generally the emission scenarios of IPCC's "Special Report on Emission Scenario" (IPCC, 2007) are used to project the future distribution of plant species. These emission scenarios are grouped into 4 families (A1, A2, B1 and B2) that explore alternative development pathways, covering a wide range of demographic, economic and technological driving forces and resulting greenhouse gases (GHG) emission (IPCC, 2007). The four families of IPCC 4 emission scenario are:

- A1 – The A1 storyline and scenario family consider a future world of very rapid economic growth, global population that peaks in mid-century and declines thereafter, and the rapid introduction of new and more efficient technologies. This scenario family is further grouped into 3 distinguished by their technological emphasis: A1F1 (fossil intensive), A1T (non-fossil energy source) and A1B (balance across all sources).
- A2 – The A2 storyline and scenario family consider a very heterogenous world with increasing population and slower economic growth.
- B1 – The B1 storyline and scenario family consider a convergent world with same global population as A1, but with rapid change in economic structures towards a service and information economy, as well as reduction in material intensity and the introduction of clean and resource-efficient technologies.
- B2 – The B2 storyline and scenario family emphasize world with increasing global population, intermediate economic development and less rapid and more diverse

technological change than in A1 and B1 storyline. It also emphasize local solution to economic, social and environmental sustainability.

The emission projections are extensively used in the assessments of future climate change and their underlying assumption with respect to socio-economic demographic and technological change (IPCC, 2007).

Here SRES-A1B scenario was used as it is the baseline scenario to project upto 2050. It is balance across all sources. This baseline scenario is specified only to 2100. After then, the emissions of gases other than CO₂ are assumed to remain constant at their SRES-A1B 2100 values. (IPCC, 2007)

1.2 Literature review

Species Distribution Modelling (SDM) and Ecological Niche Modelling (ENM) have been extensively used to refer to correlative summaries of species environmental associations and the relationships of those associations to their geographic distributions (Araujo and Peterson, 2012). There are a number of modelling technique and algorithm to predict the probability of the species occurrences by the environmental variables as limiting factors for species survivals.

A lot of work has been done worldwide to predict the potential of habitat modelling of plant species to understand the contribution of climatic variable of a particular species. These studies have set center stage for research on future prediction of ecological niche and other issues like presence and pseudo absence scientific data.

The history for species distribution and ecological niche dates back to 1917 A.D. but the work regarding species distribution and ecological niche modelling started late 1990's. After 2000 A.D. tremendous work on species distribution modelling was carried out throughout the world and huge number of published paper are available. Those papers are published in number of science indexed journal which are available for wide range of reader, in addition to those numbers of thesis/dissertation on species distribution modelling are available through google scholar.

Though several hundred modelling are available, which predict distribution of various species in the world but very few work has been done in Nepal, e.g. Ranjitkar *et al.* 2014a, Ranjitkar

et al. 2014b, Shrestha and Bawa, 2014. In Nepal, the works related to distribution or ecological niche of Alder species have not done yet. But some research work regarding Carbon sequestration potential of *Alnus nepalensis* in mid hills (Ranabhat *et al.*, 2008); Monitoring growth of Uttis (*Alnus nepalensis*) at a plantation site at Dhankuta, Nepal (Barakoti, 2005), etc. was done. Beside that, Genetic diversity, distribution pattern, germination and ethnobotanical uses of *Alnus nepalensis* and *Alnus nitida* in Lumle and Pokhara region of Nepal by ICIMOD (Prasad and Shah, 1997) was also done but it was unpublished.

Ranjitkar *et al.* (2014a) used an SDM ensemble method in the BiodiversityR R-package to identify the bioclimatic variable that defines the climate space for Trans-Himalayan Nyctaginaceae species *Boerhavia diffusa* and *Oxybaphus himalaicus*. They concluded the most favourable conditions for *B. diffusa* were centrally located at well-drained and hot lowlands of Nepal whereas that of *O. himalaicus* was located in highlands valleys.

Shrestha and Bawa (2014) used MaxEnt modelling to predict current distribution and changes in the future distributions of Chinese caterpillar fungus (*Ophiocordyceps sinensis*) in three future climate change trajectories based on representative concentration pathways (RCPs: RCP 2.6, RCP 4.5, and RCP 6.0) in three different time periods (2030, 2050, and 2070) using species occurrence points, bioclimatic variables, and altitude. They found about 6.02% (8,989 km²) area of the Nepal Himalaya is suitable for Chinese caterpillar fungus habitat. The model showed that the area of predicted suitable habitat of Chinese caterpillar fungus would expand, with 0.11–4.87% expansion over current suitable habitat.

Selected SDM works in different part of the world

Vargas *et al.* (2004) used herbarium specimen data and GIS software to model the potential distribution of 36 endemic and 47 non-endemic species of *Anthurium* (Araceae) in Ecuador based on mean annual temperature and humidity. They found that the important region for endemics in western Ecuador lies between the Andes and Coastal mountain ranges between 200 and 700 m, while for eastern Ecuador a belt of potential high diversity occurs directly along the foothills of the Andes under 1000 m.

Saqib *et al.* (2006) used Domain model to produce potential distribution map of *Taxus wallichiana* in Palas valley. The model produced that the distribution of *Taxus wallichiana* is

scanty and patchy in Palas valley. The core habitat of species was defined from the similarity index cutoff of 0.95 – 1. Overall accuracy of the predictive model was 87.2%.

Babar *et al.* (2012), used ecological niche modelling approaches, namely GARP, Maxent and BIOCLIM for predicting potential areas of occurrence based on field sample-based distributional information, in relation to climatic and topographic datasets in the forest tracts of Chittoor and Kadapa districts. GARP appeared to be more robust in prediction capabilities compared to BIOCLIM. The potential distributional area identified by these models falls mainly in regions not protected and experiencing high anthropogenic pressure owing to economic and medicinal use. The success of this model indicated that ENM-based approaches provide a promising tool for exploring various scenarios useful in the study of ecology, biogeography and conservation.

Slater and Michael (2012) predicted a broad geographic distribution of *Lymphatic Filariasis* using MaxEnt in Africa extending from the west to the east across the middle region of the continent, with high probabilities of occurrence in the Western Africa compared to large areas of medium probability interspersed with smaller areas of high probability in Central and Eastern Africa and in Madagascar.

Sakalli (2013) presented a new method and model to predict the distribution of N₂-fixing genus *Alnus* on global scale. The model (*Alnus*-Distribution-Model, ADM) was also developed to predict the impact of climate change on alder distribution by using climate data of five relevant climate models (PCM, ECHam4, HadCM3, CSIRO2 and CGCM2), and four IPCC climate scenarios (i.e. A1FI, A2, B1 and B2) in 2100. He found that alder has a large potential distribution areas in Asia and North America. The results showed that the alder can extend its distribution northwards. The scenarios A1FI and A2 as well as B1 and B2 in all five climate models showed globally quite the same effect on the alder distribution.

1.3 Rationale of the work

For biogeographer, modelling species ecological niche and its potential distribution is becoming a powerful tool in recent years (Ranjitkar *et al.*, 2014b). Understanding where species occur is fundamental to understand their biology, and prediction of occurrence is essential for conservation and agroforestry systems. This work will be the best approach linking statistic with systematic, biogeography, ecology. In Nepal, study of climatic variables

on modelling the ecological niche of species is virtually absent. This work will fill that gap by analyzing different habitat/niche of *Alnus* species in response to different environmental variables and predict the distribution by using Machine learning software MaxEnt. The potential habitat of *Alnus nepalensis* and *Alnus nitida* for current and future 2050 (based on IPCC scenario SRES-A1B) will be useful for determining the suitability of agroforestry region specially intercropping for *Alnus*-cardamom, *Alnus*-Tea, or other *Alnus* based agroforestry system in different locations in Nepal. The numerous scenarios are available to make the prediction. But, SRES-A1B scenario is the baseline scenario which balances across all sources. This baseline scenario is specified only to 2100. After then, the emissions of gases other than CO₂ are assumed to remain constant at their SRES-A1B 2100 values.

1.4 Limitations

Ecological niche modelling requires sufficient number of occurrence points that represents different environments. These occurrence points are gathered either from the field expedition or from herbarium of different herbaria. The georeferenced presence points from the herbarium record and field expeditions might not represent accurate occurrence due to failure of GPS. These errors create uncertainty in the species distribution. The increasing occurrence points also create spatial autocorrelation as well less occurrence points also creates under prediction. Here, the herbarium records of *A. nepalensis* and *A. nitida* were taken from different herbaria, which are geographically confined to varying range of area i.e. wide range and narrow range respectively. Certain species have specific ecological limitations governing where they are known to occur, which may result in over-prediction of suitable habitat by the model.

There are very less research work on species distribution and ecological niche modelling in Nepal. The present work uses MaxEnt model that utilizes a statistical mechanics approaches called Maximum Entropy to make prediction from incomplete data. During the course of predicting, because of extrapolation the areas predicted by the model are quite larger than actual area of species occurrence, which should be carefully interpreted for developing effective management of the focal species.

1.5 Objectives

The general objective of the study is to model the ecological niche by relating sites of known occurrence (and pseudo-absence) with predictive environmental variables known for the sites of *Alnus* species (*A. nepalensis* and *A. nitida*) for current and future. The specific objectives are:

- a. To obtain the best model that defines the distribution of *Alnus* species.
- b. To forecast the geographic distribution and ecological niche of *Alnus* species using environmental variables.
- c. To analyze the bioclimatic variable important for *Alnus* distribution.
- d. To forecast the potential distribution of *Alnus* species in 2050.

1.6 Research hypothesis

The present work formulated hypothesis to test the significance of the model (hypothesis 1) and compare the means of the models (hypothesis 2).

Hypothesis 1.

Testing the hypothesis that the models produced for each species are significantly better than a random model

H_0 : AUC (train) and AUC (test) = 0.5

H_1 : AUC (train) and AUC (test) > 0.5

Hypothesis 2

H_0 : $AUC_1 = AUC_2$;

H_1 : $AUC_1 \neq AUC_2$; where, AUC_1 = models with climatic variables and AUC_2 = model that include topographic variables

1.7 Conceptual frame work

The research work is based on the framework derived from the concerned research work on species distribution in Asian Highlands (World Agroforestry Centre CRP 6.2 program). The conceptual framework of present research work is outlined as below:

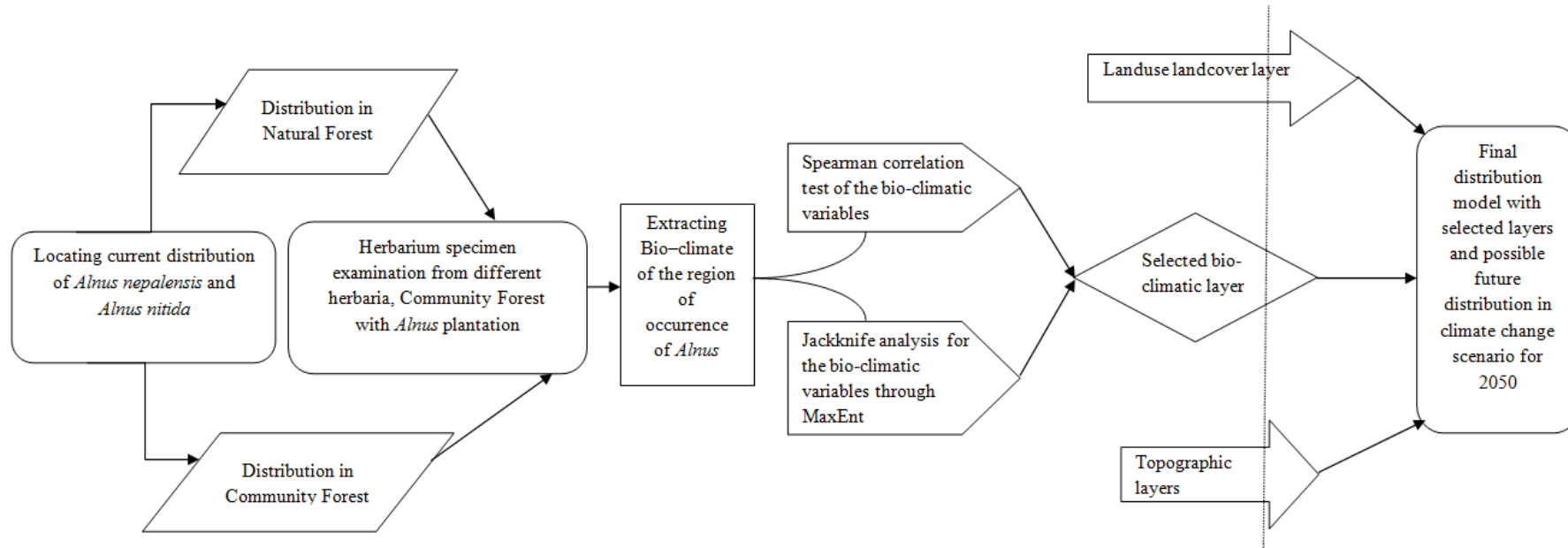


Fig. 1.1 Conceptual framework of the present work.

CHAPTER 2

MATERIALS AND METHODOLOGY

2.1 Study area

The present work was carried out within political boundary of Nepal representing the distribution of Alder forests from east to west and north to south (**Fig. 2.1**). The whole work was based on the herbarium collected location points from different herbaria and their databases. This location points represents only the extents of Nepal.

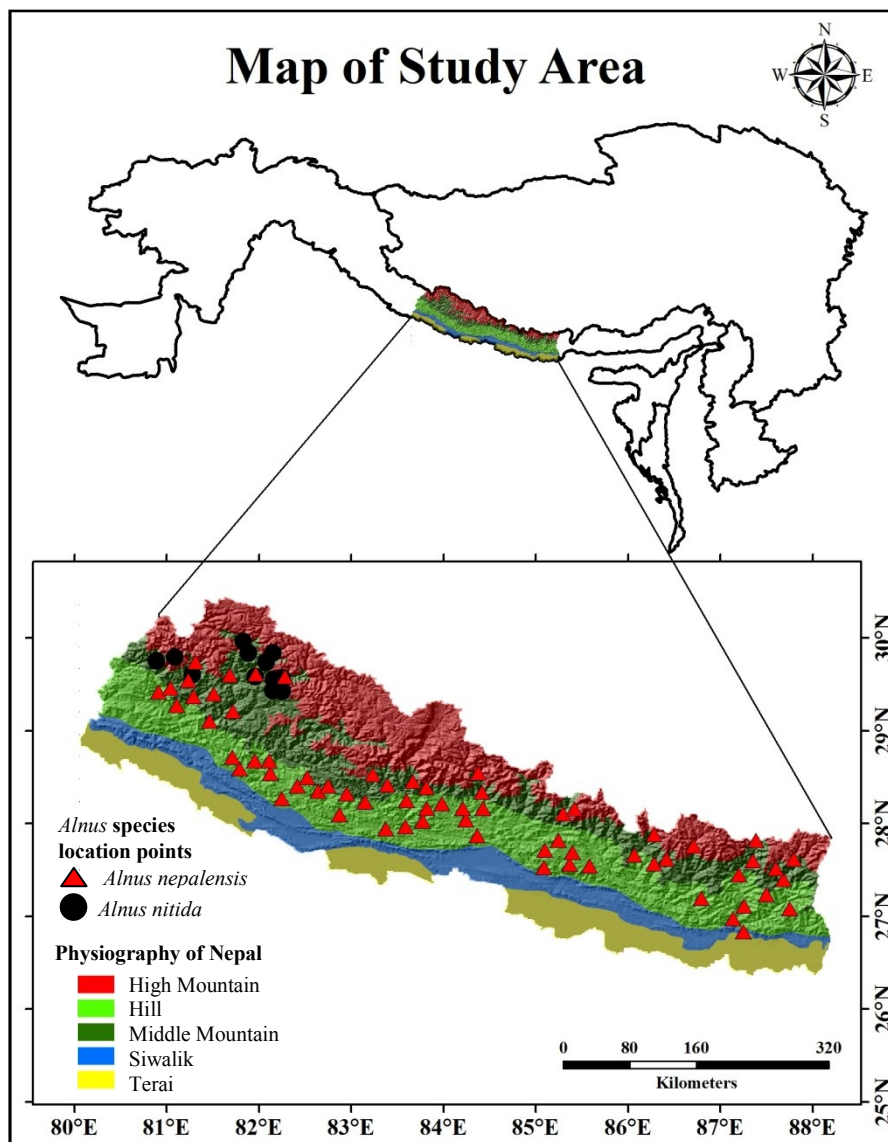


Fig. 2.1 Map of the Hindu-kush Himalayas representing distribution location of focal species in Nepal and position of Nepal (study area) showing coordinate grid within the region.

2.1.1 Geographic location

Nepal is situated on the southern slopes of the central Himalayas and occupies a total area 1, 47,181km². The country is located between latitudes 26°22' and 30°27' N and longitudes 80°40' and 88°12' E. Hills and high mountains cover about 86% of the total land area and the remaining 14% are the flatlands of the Terai, which are less than 300m in elevation. Altitude varies from some 60m above sea level in the Terai to Mount Everest (Sagarmatha) at 8,848m, the highest point in the world. (HMGN/MFSC, 2002)

2.1.2 Physiography

Physiography of Nepal has been mainly divided on the basis of river, relief, structure altitude and geographical distribution, resulting in distinct landform and topography. For the sake of convenience, the physiography of Nepal is divided as High Himal, High Mountain, Middle Mountain, Siwalik and Terai from north to south. Wide altitudinal variations and diverse climatic conditions have resulted in four main physiographic zones. The extreme altitudinal gradient has resulted in nine bio-climatic zones from tropical to nival within a short horizontal span. (HMGN/MFSC, 2002)

According to Hagen (1998), Nepal has seven physiographic divisions, which are from south to north: Terai, Siwalik Hills zone, Mahabharat Lekh, Himalaya, Inner Himalaya and Tibetan marginal mountains.

2.1.3 Climate

A wide range of climatic conditions exists in Nepal mainly as a result of altitudinal variation. This is reflected in the contrasting habitats, vegetation, and fauna that exist in the country. The High Himalayan region is always below freezing whereas the Terai and the low valleys are always warm. The mean annual maximum temperature increased by 0.6 °C per decade during 1977-2000 (Shrestha *et al.*, 1999; Shrestha and Bawa, 2014).

2.1.4 Rainfall

Eighty percent of precipitation falls during June to October. The monsoon enters Nepal from the east which receives the first rain; the west gets rain about a week later. The western part

receives comparatively less rain than central and eastern parts. The average rainfall in the country is a little above 1,000 mm. Rainfall data from meteorological stations show that the country receives as high as 5100 mm and as low as 250 mm rain per annum. (HMGN/MFSC, 2002)

2.1.5 Temperature

Temperature varies with topographic variations. For a rise of 100 m, the mean annual temperature drops by 0.5 °C. Latitude also affects the temperature. For every 3° north, the mean temperature would fall by 1 °C. Temperature falls slowly during the monsoon because of heavy clouds and rain and continues to drop as winter starts. In the Terai, winter temperatures are between 22- 27 °C, while summer temperatures exceed 37°C. (HMGN/MFSC, 2002) In the Mid-hills, temperatures are between 12-16°C. In general, the average temperature decreases by 6°C for every 1,000m gain in altitude (Jha, 1992).

2.1.6 Aspect

Aspect has an important influence on vegetation, particularly at lower altitudes. In general, moisture is retained more on north and west faces, while south and east faces are drier because of their longer exposure to the sun.

2.1.7 Land use Land cover

The latest physiographic data show that Nepal comprises around 4.27 million hectares (29% of total land area) of forest, 1.56 million hectares (10.6%) of scrubland and degraded forest, 1.7 million hectares (12%) of grassland, 3.0 million hectares (21%) of farmland, and about 1.0 million hectares (7%) of uncultivated lands (HMGN/MFSC, 2002). It has been reported (HMGN-DFRS, 1999) that forest cover in the Terai and hill areas decreased at an annual rate of 1.3% and 2.3% respectively between 1978/79 and 1990/91. The GLC 2000 classified the 12 LULC types of Nepal out of 22 global types. (See Appendix 1)

2.1.8 Forest ecosystems

Forests play a vital role in maintaining ecological balance and economic development.

Pristine forests are also a major attraction for foreign tourists. Major energy sources, animal fodder and timber are all found in the forest environment. Rural people are very dependent on many non-timber forest products (NTFPs) for their subsistence needs.

Forest types

Nepal has a very diverse flora with 35 forest types, as classified by Stainton (1972). These forest types are categorized into ten major groups - tropical, subtropical broad-leaved, subtropical conifer, lower temperate broad-leaved, lower temperate mixed broad-leaved, upper temperate broad-leaved, upper temperate mixed broad-leaved, temperate coniferous, sub-alpine and alpine scrub forests. Among the major groups, *Alnus* species thrives in broadleaved forest. *Alnus nepalensis* mostly occur in Subtropical broadleaved forest (1,000 – 2,000 m) alongwith Schima-Castanopsis forest. The *Alnus* forests are widespread along streams and in moist places. *Alnus nitida* are confined to the lower temperate broadleaved forest (2,130-2,440 m) especially in the river banks of the Mugu-Karnali region. *A. nitida* mostly occur in Western Himalaya alongwith Castanopsis-Quercus species. A number of districts now have substantial areas of plantation forest comprising both indigenous and exotic species. *Dalbergia sissoo*, *Eucalyptus* species and *Tectona grandis* were planted in Terai districts and *Pinus roxburghii*, *P. wallichiana*, *P. patula* and *Alnus nepalensis* were planted in the Mid-hills (HMGN/MFSC, 2002; Singh *et al.*, 2010).

2.2 Materials

2.2.1 Source of data

The study involved procurement of world-clim data, survey, on screen visual interpretation for the assessment of potential niche modelling using different data (see Appendix 2).

- Bio-climatic layer for current (1950 – 2000) and future (2050) SRES-A1B scenario were downloaded from World-clim (<http://worldclim.org/download>; Hijmans *et al.*, 2005) at the spatial resolution of 1 km (30 arc~seconds) with the same extent, resolution and cell size.

- The Aster Digital Elevation Model (DEM) (www.eros.usgs.gov) was used to create other topographic variables like slope, aspects, and terrain roughness. The entire layer has the same extent of Nepal, resolution of 30 arc~sec and cell size as that of climatic layers.
- Landuse landcover (LULC) datasets downloaded from GLC (Global Landcover) 2000 (<http://www.diva-gis.org/gdata>) and was used as constant variable.
- Species location data for *Alnus* species was compiled from herbarium specimen housed in Tribhuvan University Central Herbarium, TU and The National Herbarium and Plant Laboratory in Kathmandu. The online database of the Royal Botanical Garden at Edinburgh, United Kingdom, and Herbarium at the University of Tokyo, Japan were the major source (Appendix 3). Some of the location data are gathered from the previous field works.

2.2.2 Instruments

The instruments used during the field survey were:

- GPS (Global Positioning System), Camera

2.2.3 Software

Following software were used for data interpretation, image processing, analysis.

- ArcGIS 10.2.1 for database creation and analysis
- MS-OFFICE 2007 for data compilation and report preparation
- R-statistical environment integrated with R- studio v.0.97.449- for statistical analysis
- MaxEnt v 3.3.3k (Maximum Entropy) for niche modelling

2.2.4 Focal species

The present work is related to distribution and ecological niche modelling of multi-purpose *Alnus* species. *Alnus* commonly known as Alder is an important plant group because of its N₂-fixation ability. Alder is the common name of a genus of flowering plants belonging to the birch family.

Alder species are found from east to west ranging from hilly region to high hills. In Nepal there are two species of *Alnus* i.e. *Alnus nepalensis* D.Don and *Alnus nitida* (Spach) Endl. where *Alnus nepalensis* is native to Eastern Himalayas and *Alnus nitida* is native to Western Himalayas (Sheikh, 1993), while both of these species grow in the central and western Himalaya (Sharma *et al.*, 1998; Bhattarai, 2008). Geographically they are found in distinct habitat. Alders are sturdy and fast-growing, even in acidic and damaged sites such as burned areas and mining sites. At high altitudes along the upper Karnali river, the forest is dominated by *Alnus nitida*. It grows well in moist situation on sandy soils. But *Alnus nepalensis* are distributed throughout the hilly region. It naturally regenerates in freshly exposed landslide affected soils, degraded and disturbed sites. It is either planted or grown in Cardamom-based agroforestry systems.

The detail taxonomic description based on herbarium specimen deposited at KATH and TUCH as well as literature was conducted to distinguish the *Alnus* species morphologically.

2.3 Methods

2.3.1 Species presence and pseudo-absence (background) data

This is often most time consuming part of distribution modelling. There must be sufficient number of occurrence records that documents presence (and perhaps pseudo-absence) of the species (Barbet-Massin *et al.*, 2012). Presence only methods are necessary because absence of species is difficult to demonstrate as well as false absence can decrease the reliability of predictive models. Predicting species distributions from presence-only datasets and pseudo-absences has the potential to be a useful alternative when presence/absence data are unavailable or impossible to obtain (Guisan and Thuiller, 2005). Among the attempts to evaluate presence-only models, Hirzel *et al.*, (2006) identified the approaches to generate pseudo-absence and apply standard presence/absence technique.

A database of occurrence of both species *Alnus nepalensis* and *Alnus nitida* was prepared based on herbarium specimen deposited in major herbaria around the world those hosted collections from Nepal. Herbarium specimen collection (from 1968 to 2012), expedition, reports, local floras, published articles and GPS points recorded through field survey were the main source for georeferenced occurrence points. Herbarium specimen preserved at Tribhuvan

University Central Herbarium, TU (TUCH) and The National Herbarium and Plant Laboratory in Kathmandu (KATH) were primarily examined (Appendix 3). Further, open access digital herbarium databases from Royal Botanic Garden, Edinburgh (RBGE) and the Herbarium at University museum, University of Tokyo (TI) were the important source of occurrence data (Appendix 3). For *Alnus nepalensis*, herbarium specimen of KATH (52) and TUCH (7) were examined, database of RBGE with 14 and TI with 63 occurrence locations were listed. Several GPS points were also recorded from field survey in different places. *A. nitida* as compared to *A. nepalensis* has less collection because it is confined to only western Himalayan region of Nepal. Altogether, 15 herbarium specimens of this species from KATH and 3 from digital database of RBGE were listed.

Information from the herbarium specimen collection was used with caution to prevent geocoding errors, confused taxonomic status and morphological characters (Ranjitkar *et al.*, 2014a). Even some of the duplicates sample collections from same localities were discarded for occurrence points. All the recorded points for duplicate records were checked in different spatial grid of 2 min, 4 min and 10 min resolution. Finally suitable resolution grid was chosen and the duplicate records present within them were removed. It is difficult to confirm the species being absent in any locations. So, following Barbet-Massin *et al.*, (2012) background or pseudo-absence points were selected. For the calibration of the model, random background points within an area of 50 km radius from the point of occurrence was selected for both species. For *A. nepalensis* 546 and for *A. nitida* being confined to small area 50 random background points were selected to run Moran's I test in Arc GIS 10.2.1 to check spatial autocorrelation of the species distribution. Moran's I test was performed using binary presence/absence data for two species separately.

2.3.2 Selection of predictive variables

2.3.2.1 Bioclimatic variables

The global climate data for current as well as for IPCC SRES-A1B for 2050 downloaded from Worldclim datasets of bioclimatic layers was clipped to extent of Nepal. In addition to, Global Aridity Index, Global Potential Evapo-transpiration layers (www.csi.cgiar.org) were downloaded at spatial resolution of 30 arc~sec and clipped to an extent of Nepal. These all layers were rasterized at same spatial resolution, extent, and cell size as all other layer to

match the modelling spatial resolution and projected into the working projection of WGS 1984. The derived bioclimatic variables are tabulated in Table 2.1.

2.3.2.2 Landuse landcover

The global landcover 2000 downloaded from Diva-GIS website in a grd format with spatial resolution of 30 arc~sec was clipped to extent of Nepal. It was rasterized at same spatial resolution, extent, and cell size as all other layer to match the modelling spatial resolution and projected into the working projection of WGS 1984. This layer was used in current distribution modelling as well as future projection considering that there is no change in LULC i.e. keeping LULC layer as constant. The LULC layer of Nepal consist 12 categories out of 22 categories provided by GLC 2000. (See Appendix 1)

Table 2.1 Description of bioclimatic variables

Abb	Variables name	Source
bio_1	Annual Mean Temperature	www.worldclim.org
bio_2	Mean Diurnal Range (Mean of monthly (max temp - min temp))	www.worldclim.org
bio_3	Isothermality (Bio_2/Bio_7) (* 100)	www.worldclim.org
bio_4	Temperature Seasonality (standard deviation *100)	www.worldclim.org
bio_5	Max Temperature of Warmest Month	www.worldclim.org
bio_6	Min Temperature of Coldest Month	www.worldclim.org
bio_7	Temperature Annual Range (Bio_5 – Bio_6)	www.worldclim.org
bio_8	Mean Temperature of Wettest Quarter	www.worldclim.org
bio_9	Mean Temperature of Driest Quarter	www.worldclim.org
bio_10	Mean Temperature of Warmest Quarter	www.worldclim.org
bio_11	Mean Temperature of Coldest Quarter	www.worldclim.org
bio_12	Annual Precipitation	www.worldclim.org
bio_13	Precipitation of Wettest Month	www.worldclim.org
bio_14	Precipitation of Driest Month	www.worldclim.org
bio_15	Precipitation Seasonality (Coefficient of Variation)	www.worldclim.org
bio_16	Precipitation of Wettest Quarter	www.worldclim.org
bio_17	Precipitation of Driest Quarter	www.worldclim.org
bio_18	Precipitation of Warmest Quarter	www.worldclim.org
bio_19	Precipitation of Coldest Quarter	www.worldclim.org
ai_ann	Aridity index (annual)	www.esi.cgiar.org
pet_ann	Potential Evapo-transpiration (annual)	www.esi.cgiar.org

2.3.2.3 Topographical data

Predictive models developed for mountainous terrain are usually based partially on topographic factors (Moore *et al.*, 1991; Guisan *et al.*, 1999). According to Guisan and Zimmerman (2000), the main requirements of distribution modelling is the DEM. The Aster DEM downloaded at spatial resolution of 30 arc~sec was clipped to an extent of Nepal. Slope in degrees, Aspects and terrain roughness were calculated using the Spatial Analyst Tool in Arc GIS 10.2.1.

Slope thus calculated from DEM was further reclassified to 5 categorical groups and resampled as original DEM layer.

Aspects was subsequently converted into Eastness and Northness to produce two layers as shown in equation 1 and 2 according to Deng *et al.* (2007).

$$\text{Northness} = \cos(\text{aspect}) \dots \dots \dots \text{eq (1)}$$

$$\text{Eastness} = \sin(\text{aspect}) \dots \dots \dots \text{eq (2)}$$

This conversion results in values ranging from -1 to 1 for both values of Northness and Eastness. This values represents the extent to which slope faces north (1), south (-1), east (1) or west (-1). This conversion is to facilitate quantitative analyses since aspects was originally calculated as circular degrees clockwise from 0 to 360, which is difficult to compare because 0 and 360 signify the same aspect. Northness and Eastness have therefore been used in this work rather than the circular-linear correlation because they have been found to be more intuitive and more convenient for comparison with other topographic attributes (Deng *et al.*, 2007).

Terrain roughness was calculated from DEM using the formula:

$$\text{Terrain roughness} = \frac{\text{mean} - \text{min}}{\text{max} - \text{mean}}$$

where,

mean = layer of mean elevation

max = layer of maximum elevation

min = layer of minimum elevation

These three layers of mean, maximum and minimum were prepared separately using the Spatial Analyst Tool in Arc GIS 10.2.1 and used in Raster calculator to create layer of Terrain roughness. Thus, the final layer is resampled same as DEM.

Finally all the 26 layers (21 bioclimatic, 4 topographic and 1 LULC) were converted into ASCII format with the same projection, extent and resolution (Appendix 2).

2.3.2.4 Predictive variable preparation

Out of 26 variables, few significant variables were selected for each species considering their contribution in the model, importance, co-linearity among variables and biological significance for the particular species.

To obtain a set of functionally relevant predictors, all the 21 bioclimatic variables were feed to MaxEnt model along with species occurrence record. MaxEnt jackknife test of variables importance was used to evaluate the relative strength of each predictor variables (Yost *et al.*, 2008) (Appendix 4, Fig. a and Fig. b). Several test run were performed for both species setting the MaxEnt to select at random 75% of the occurrences for training and 25% for testing. The model was set according to MaxEnt setting. The training gain was calculated for each variable alone and the drop in training gain was calculated when the variable was omitted from the full model. Therefore, those variables that didn't produce a decrease greater than 0.01 in the average training gain when they were omitted were removed. The variable contribution for each variable was analyzed (Appendix 4, Table c). Each variable with maximum entropy (% contribution >2) were chosen.

Furthermore, exclusion of the variables was carried out by examining co-linearity among variables. Among the two highly correlated variables (Pearson correlation coefficient, $r > 0.80$), one was chosen considering its biological relevance to the species and ease of interpretation for inclusion in the model (Kumar and Stohlgren, 2009). Topographic and LULC not being correlated to each other, they were not performed Pearson correlation test (Table 2.2). Resultantly, significant variables were selected for modelling potential habitat suitability considering for both *Alnus nepalensis* and *Alnus nitida*. Finally, the least correlated variables excluding the highly correlated variables are selected. The selected predictive variables used as input from the Pearson correlation and Jackknife analysis are tabulated in Table 2.3.

Table 2.2 Cross correlation (Pearson correlation coefficient, r) among Bioclimatic variables performed using Biodiversity R statistical software.

Pearson Correlations Coefficient (r)																					
variables	bio_1	bio_2	bio_3	bio_4	bio_5	bio_6	bio_7	bio_8	bio_9	bio_10	bio_11	bio_12	bio_13	bio_14	bio_15	bio_16	bio_17	bio_18	bio_19	ai_ann	pet_ann
bio_1	1.000																				
bio_2	0.333**	1.000																			
bio_3	0.003	0.324**	1.000																		
bio_4	0.231	0.551**	-0.586**	1.000																	
bio_5	0.959**	0.459**	-0.143	0.460**	1.000																
bio_6	0.980**	0.192	-0.014	0.121	0.927**	1.000															
bio_7	0.342**	0.773**	-0.342**	0.936**	0.564**	0.214	1.000														
bio_8	0.997**	0.364**	0.003	0.263*	0.960**	0.966**	0.373**	1.000													
bio_9	0.988**	0.278*	0.013	0.175	0.938**	0.982**	0.280*	0.981**	1.000												
bio_10	0.997**	0.370**	-0.039	0.302*	0.975**	0.970**	0.407**	0.997**	0.981**	1.000											
bio_11	0.996**	0.288*	0.059	0.141	0.934**	0.987**	0.260*	0.990**	0.989**	0.986**	1.000										
bio_12	0.402**	-0.119	0.235	-0.294*	0.253*	0.417**	-0.261*	0.396**	0.418**	0.362**	0.430**	1.000									
bio_13	0.381**	-0.061	0.204	-0.218	0.247*	0.374**	-0.179	0.381**	0.389**	0.346**	0.401**	0.982**	1.000								
bio_14	0.016	-0.252*	-0.253*	0.035	0.041	0.087	-0.085	0.011	0.017	0.026	0.018	-0.003	-0.107	1.000							
bio_15	0.258*	0.217	0.114	0.086	0.189	0.146	0.170	0.283*	0.219	0.246*	0.243*	0.498**	0.628**	-0.502**	1.000						
bio_16	0.396**	-0.061	0.225	-0.238	0.257*	0.392**	-0.194	0.393**	0.405**	0.358**	0.417**	0.989**	0.997**	-0.108	0.605**	1.000					
bio_17	-0.070	-0.195	-0.621**	0.374**	0.093	0.009	0.222	-0.086	-0.061	-0.033	-0.099	-0.275*	-0.343**	0.733**	-0.614**	-0.344**	1.000				
bio_18	0.222	-0.159	0.410**	-0.469**	0.041	0.238	-0.419**	0.216	0.244*	0.173	0.263*	0.944**	0.936**	-0.135	0.510**	0.943**	-0.448**	1.000			
bio_19	-0.162	-0.106	-0.644**	0.476**	0.040	-0.099	0.321**	-0.176	-0.147	-0.117	-0.202	-0.374**	-0.420**	0.579**	-0.613**	-0.424**	0.961**	-0.528**	1.000		
ai_ann	0.032	-0.407**	0.221	-0.505**	-0.144	0.074	-0.538**	0.025	0.057	-0.016	0.074	0.901**	0.882**	0.054	0.414**	0.881**	-0.252*	0.918**	-0.358**	1.000	
pet_ann	0.967**	0.538**	0.055	0.362**	0.975**	0.922**	0.512**	0.970**	0.946**	0.976**	0.951**	0.302*	0.298*	-0.017	0.248*	0.309*	-0.050	0.123	-0.108	-0.096	1.000

*. Correlation is significant at the 0.05 level (2-tailed).

** . Correlation is significant at the 0.01 level (2-tailed).

Note: highlighted cells indicate highly correlated variables.

Table 2.3 Environmental variables used as input in modelling.

Category	Variables name	Abb	Attribute	Resolution	Source
Climate	Isothermality (bio_2/bio_7)*(100)	bio_3	Continuous	30 arc~ sec	worldclim data
	Temperature Seasonality (standard deviation *100)	bio_4	Continuous	30 arc ~ sec	worldclim data
	Min Temperature of Coldest Month	bio_6	Continuous	30 arc ~ sec	worldclim data
	Mean Temperature of Driest Quarter	bio_9	Continuous	30 arc ~ sec	worldclim data
	Precipitation Seasonality (Coefficient of Variation)	bio_15	Continuous	30 arc ~ sec	worldclim data
	Precipitation of Driest Quarter	bio_17	Continuous	30 arc ~ sec	worldclim data
	Precipitation of Warmest Quarter	bio_18	Continuous	30 arc ~ sec	worldclim data
Topographic	Slope	Slope	Categorical	30 arc ~ sec	DEM
	Aspects (Northness)	Northness	Continuous	30 arc ~ sec	DEM
	Aspects (Eastness)	Eastness	Continuous	30 arc ~ sec	DEM
	Terrain roughness	t_rgh	Continuous	30 arc ~ sec	DEM
LULC	Landuse landcover	LULC	Categorical	30 arc ~ sec	GLC2000

2.3.3 Algorithm used

The model selected to determine the ecological niche of *Alnus* species (Betulaceae) is MaxEnt 3.3.3k (Maximum Entropy) developed by S. Phillips and colleagues freely available at <http://www.cs.princeton.edu/~schapire/maxent/> .

MaxEnt is a general purpose machine learning programme and has been widely used to predict species distributions (Peterson *et al.*, 2007; Phillips *et al.* 2006; Phillips *et al.*, 2008). MaxEnt use only presence data in combination with environmental data for the whole study area to derive a model and predict suitable condition or ecological niche. Based on the presence data and the relation of the presence data with the environmental variables, MaxEnt assigns a non-negative probability to all pixels in the study area (Phillips, 2005; Phillips *et al.*, 2004). The approach aims to find the probability distribution of maximum entropy (that which is closest to uniform), incorporated by the observed spatial distribution of species and environmental conditions. MaxEnt thus outputs the maximum entropy distribution that satisfies these constraints, thereby providing the least biased description for a given datasets. (Phillips *et al.*, 2006)

2.3.4 MaxEnt setting for current work

The freely available MaxEnt software 3.3.3k was used to generate an estimate of probability of presence of the species that varies from 0 to 1, where 0 being lowest and 1 being the highest probability.

The MaxEnt model requires point location where species are known to occur. The environment layer as predictors might limit the species capabilities to survive in that location. The inputs for the model run were the predictor raster layers with same projection, extent and resolution and the species presence records, representing the location of focal species. For species presence data to feed into model, three column sheets was prepared that includes species scientific name, longitude (X-coordinate) and latitude (Y-coordinate).

For the model calibration, the selected predictive variables were used for both species of *Alnus*. Altogether 50 replicates of model with least-correlated set of variables were run, setting MaxEnt to select at random 75% of occurrences localities at each run for training and leaving the remaining 25% for testing at each run. The user specified parameters were set as

regularization multiplier = 1, maximum iteration = 5000, convergence threshold = 0.0001, maximum background points = 10,000, replication 50 and uses linear, quadratic, product threshold and hinge features. As output, a predicted distribution map in the ESRI raster grid format is averages, minimum, maximum, median and standard deviation. The average output was chosen for spatial analysis.

2.3.5 Forecasting current suitable niche

To predict the current distribution of the two species of *Alnus* with MaxEnt, all the environmental layers are required to be in the same projection, extent and resolution and need to be converted into ASCII format. The occurrence records were prepared in excel and saved as comma separated values (csv). Each species present record was randomly used for 50 replicates. Each replicate was created by randomly selecting 75% of the presence records for training the model and 25% for testing. The remaining setup was done as per the MaxEnt default. These replicates allowed for the assessment of the average behavior of the models and also for the statistical testing of observed differences in performance of the models as proposed by Phillips *et al.* (2006). Fifty sub-models were produced for each species which were averaged to get final model for focal species. Thus a total of 50 output maps were produced for each model. The average probability of suitability was used for each species based on the 50 output maps produced.

To test whether the predictive variables improved the modelling significantly, four separate categories of models were generated for each species (in a stepwise manner). The first model used was based on bioclimatic variables (Model 1). This is the lowest level of the modelling with only predictive bioclimatic variables. For Model 2, bioclimatic variables and topographic variables were used as predictors. The Model 3 was generated using bioclimatic variables and LULC. Finally, Model 4 was built using combination of bioclimatic variables, topographic variables and LULC (Table 2.4). The model was performed in this way to allow for the effect at each stage to be quantified in terms of the gain and AUC. Each of aforementioned models was generated following the method mentioned in section 2.3.4. Finally, the significantly better than random model was chosen among four models.

Table 2.4 Models produced under current conditions.

Model	Variables
1	Bioclimatic variables
2	Bioclimatic variables + Topographic variables
3	Bioclimatic variables + LULC
4	Bioclimatic variables + Topographic variables + LULC

2.3.6 Sensitivity analysis

A jackknife analysis was used to evaluate the relative importance of each predictor variables and the ability to correctly predict new ranges in the model. The jackknife calculates the training gain of each variable if the model was run in isolation, and compares it to the training gain with all the variables. This is useful to identify which variable contribute the most. For each environmental variable, a response curve was created. Response curves show how the variables affect the MaxEnt prediction, which indicate the values of each variable that is suitable for the study species.

2.3.7 Model evaluation

The evaluation of the accuracies of the prediction models (Hanley and Mc Neil, 1982) generated through MaxEnt was carried out selecting threshold independent Receiver Operating Characteristics (ROC) Area Under Curve (AUC) method (Liu *et al.*, 2005; Phillips *et al.*, 2008). AUC is widely used procedure for comparing species distribution model performance. The ROC is obtained by plotting sensitivity as a function of the falsely predicted positive fraction or commission error (1-specificity) for all possible thresholds of a probabilistic prediction of occurrence. The resulting area under the ROC curve provides a single measure of overall model accuracy, which is independent of a particular threshold. AUC values ranges from 0 to 1, with a value of 1 indicating the probability that when a presence site (site where a species is recorded) and an absence site (site where species is recorded as absent) are drawn at random from the population, the presence site has a higher predicted value than the absence site (Elith *et al.*, 2006; Phillips *et al.*, 2006). The AUC values from the 50 subsets produced by each model were statistically tested to determine if they were significantly better than random AUC (0.5). The averages of the AUC's were calculated and compared with different models. As noted by Phillips *et al.*, (2006), the AUC

calculated for data without true absences tends to be high for species with restricted ranges and low for wide ranging species, therefore AUC's are interpreted by considering the specie's natural distribution.

2.3.8 Future projection

To forecast how future climate may influence the potential distribution of all two species, current climate species relationship was projected onto the future estimates of climatic conditions in 2050 from the worldclim database. Changes in the habitat suitability of both species under future IPCC climatic scenario SRES-A1B were quantified by transforming the probability of occurrences from models into presence-absence maps. This was done by using the threshold that maximizes sensitivity and specificity of the test points. The changes in suitable and unsuitable conditions were then reclassified as per the binary maps as 1 for present and 0 for absence using Arc GIS 10.2.1.

For the future prediction, MaxEnt model was used with the MaxEnt setup as mentioned in MaxEnt setting (2.3.4). IPCC scenario SRES-A1B was used as the projection layer for 2050 for both the species of *Alnus*. The future prediction was done by projecting the finally selected significant model out of four models. Here LULC vegetation layer was considered as constant considering since 2000 the layer hasn't been projected. The predicted projection layers that were prepared same as current raster layer were used to project the future suitability of the focal species. The model was run separately for year 2050.

2.3.9 Statistical test of significance of model

A statistical test was carried out to

1. Test whether the average AUC's produces were better than a null or random model (with AUC of 0.5)
2. Test whether the models were significantly different from each other.

In order to decide on which test to use, a normality test was carried out in R studio v.0.97.449 to test whether the AUCs (Training and Test) for 4 model were normally distributed. Based on the normality test, a one tailed T-test was used to test for the significance of the average

AUC values against a random model. Analysis of Variance (ANOVA) was used to establish if there is any significant difference between the means of the AUC. A pair-wise comparison was then carried out to establish which two means are significantly different from each other. This statistical test gives the choice of model which is significantly better than random model.

2.3.10 Final distribution map

For the spatial analysis ArcInfo 10.2.1 (ESRI) and the extension Spatial Analysis (ESRI) was used. The output raster layer of both species of *Alnus* i.e. *Alnus nepalensis* and *Alnus nitida* from MaxEnt was imported to Arc Map in Arc GIS. Finally, to generate a binary prediction of occurrence, it was necessary to choose a threshold. Selecting a right threshold in predictive niche modelling is a difficult task and currently there are no procedures that have no degree of arbitrariness, although some methods have been proposed by Liu *et al.*, 2005. In the present work, one of the thresholds provided by MaxEnt output, specifically one that maximizes sensitivity and specificity of the test points was selected, since the methods offered an over-predicted picture of the distribution of the species analysed.

The habitat suitability of both species for current and future distribution was determined separately. Even the raster layer for each predicted variables was analysed for habitat suitability in current and future scenario. The area for all present and future grids was determined by counting the total number of corresponding pixel. I used 1 pixel count = 0.77 km² after measuring the area of a pixel using ArcGIS. For all present and future predictions, it was differentiated between stable, retracted and expanded areas with respect to present-day prediction only for SRES-A1B scenario of 2050 and finally calculated the area for each level. The area expressed in term of percentage was calculated from the total area of Nepal 1,47,181 km². Thus the area calculated is suitability projection but not actual occupying area.

In some map hillshade layer was used as the background map where flat area indicate plain land, raised part indicates mountains and shaded region indicates the shade/shadow of the hill. The hillshade layer purely indicates the actual natural distribution of the species.

2.3.11 Analysis of extent of extrapolation using multivariate environmental similarity surfaces (MESS) analysis.

The predictions of places which are not sampled in training data are usually done by measuring the similarity between the new environments and those in the training sample. MaxEnt 3.3.3k following the methodology by Elith *et al.* (2010) was used to measure the similarity of any given points to a reference set of points, with respect to the chosen predictor variables (Saupe *et al.*, 2012, Rodder *et al.*, 2013). It reports the closeness of the point. The distribution of reference points gives negative values for dissimilar points and maps these values across the whole prediction region. It indicates the novel places where the model extrapolates most. The MoD (Most Dissimilar) variable analysis predicts variables that contribute most in MESS score. Those variables extrapolate most in the model. The MESS score value ranges from positive to negative. Negative values indicate extrapolated region i.e. outside the training range (Rodder *et al.*, 2013). Positive values are similar to Bioclim values, with a score of 100 meaning that a point is not at all novel. The MoD predicts the variables for extrapolated region.

CHAPTER 3

RESULTS AND DISCUSSION

3.1 Results

This section presents results from the Taxonomic descriptions and modelling the ecological niche of *Alnus* species and a brief discussion for each result. The chapter is divided into 2 main parts:

Part I: Taxonomic description

Part II: Ecological Niche Modelling

Part I: Taxonomic description

Classification (Armen L. Takhtajan, 1980)

Kingdom: Plantae, **Division:** Magnoliophyta, **Class:** Magnoliopsida, **Order:** Fagales,

Family: Betulaceae, **Genus:** *Alnus*

APG III System of Classification (2009)

Clade: Fabid (N-Fixing Clade), **Order:** Fagales, **Family:** Betulaceae, **Genus:** *Alnus*

Alnus Miller, Gard. Dict., Abr. ed. 4, 1: 51. 1754.

Tree deciduous. Buds stalked with 2(or 3) scales or sessile with several overlapping scales. Leaves usually serrate or dentate, rarely incised or entire. Male inflorescence elongate, pendulous, cylindric, with numerous overlapping bracts, each bract subtending (3 or) 4 (or 5) bracteoles and 3 flowers; calyx 4-lobed; stamens (1–)4; anthers 2-loculed, thecae connate, apex glabrous. Female inflorescence 1, or 2–numerous in a raceme or panicle, ovoid or ellipsoid, conelike; bracts numerous, overlapping, woody, persistent, apex 5-lobulate, each bract subtending 2 flowers. Nutlets 2 in each bract axil, compressed, with membranous or papery wings.

The genus *Alnus* Miller (Betulaceae) comprises 40 monoecious trees and shrubs species (Tseng *et al.*, 2013) that are mainly distributed in the temperate climate and high altitude countries.

1. **Alnus nepalensis** D. Don, Prodr. Fl. Nepal. 58. 1825; Qi mu in Fl. China 4: 302. 1999; Press *et al.* in Ann. Check. Fl. Pl. Nep. 27. 2000.

Alnus boshia Buch.-Ham. ex D. Don; *Clethropsis nepalensis* (D. Don) Spach.

Himalayan Alder (Eng.), Utis (Nep.)

Deciduous trees to 20 m tall; bark gray or dark gray, smooth. Branchlets dark brown, sparsely yellow pubescent when young, glabrescent. Buds stipitate, with 2 glabrous, ribbed scales. Petiole robust, 1–2 cm, subglabrous; leaf blade obovate-lanceolate, obovate-oblong, ovate, or elliptic, 5–16 × 2.5–10 cm, abaxially with dense, resinous glands, yellow pubescent along veins, bearded in axils of lateral veins, adaxially glabrous, base cuneate or broadly cuneate, rarely subrounded, margin entire or remotely minutely serrate, apex abrupt or acute, rarely acuminate; lateral veins 8–14 on each side of midvein. Male catkin 10 cm x 3-5 mm in a terminal panicle to 16 cm. Female inflorescences numerous, in a panicle, ellipsoid, 2–2.2 cm × 7–8 mm; peduncle robust, 2–8 mm, glabrous; bracts ca. 4 mm, woody, persistent, base cuneate, apex rounded, 5-lobed. Nutlet oblong, ca. 2 mm, with membranous wings ca. 1/2 as wide as nutlet.

Nepalese Alder, is the most common deciduous tree species used in agroforestry practice in moist mountain area (Sharma *et al.*, 1998). It is widely used as shade tree in large cardamom (cash crop) based agroforestry (Sharma *et al.*, 1998) in Eastern Nepal. It regenerates naturally on the landslide affected freshly exposed and degraded sites. It is relatively short lived and has the capability to fix atmospheric nitrogen.

Distribution range: WCE (500–2600 m) Nepal (China, Bangladesh, Bhutan, India, Myanmar, Sikkim, N Thailand, N Vietnam)

Ecology: Riverbanks or village margins, often forming pure stands.

Flowering: May–Jun, **Fruiting:** Jul–Sep.

Specimens examined: Eastern Nepal: *Panchthar*, Lalikhaira Phidim, 2000m, 18 Nov 1978, P. Pradhan, N.P. Manandhar and N. Acharya 1055 (KATH); *Dhankuta*, Hile–Pakhribas, 1740m, 2 July 1988, M.N. Subedi 219 (KATH). (See Appendix 3).

2. **Alnus nitida** (Spach) Endl., Gen. Pl. Suppl. 4(2): 20. 1847; Press *et al.* in Ann. Check. Fl. Pl. Nep. 27. 2000.

Western Himalayan Alder (Eng.), Utis (Nep.)

Clethropsis nitida Spach.

A tree 10 m tall. Young shoots pubescent, becoming glabrescent when old. Leaves ovate to

elliptic-ovate, 6-14 cm x 3-8 cm, acute or acuminate, remotely serrate to sub-serrate, pubescent to pilose, often villous at the angles of the veins on the under surface, base cuneate to rounded; petiole 2-4 cm long, glabrous to pubescent. Male flowers in catkins, up to 14 cm long; peduncle 5-6.5 mm long; bract c. 1.2 mm long, more or less ovate, bracteoles smaller, suborbiculate. Tepals oblong-obovate to spatulate, c. 1 mm long, apex and margin minutely toothed. Anthers c. 1 mm long, filament slightly shorter than the tepals, scarcely forked. Female flowers in erect 'woody cones', 2-3.5 cm x c. 1.2 cm; Peduncle 5-6.5 mm long, bract broadly ovate, bracteoles suborbiculate. Styles 2, linear. Fruiting scale 5-lobed, 5-6 mm long, apex obliquely truncate. Nut 2.5-4 mm long, fringed by the narrow and more or less leathery wings.

Alnus nitida is commonly found along the streams or cultivated as roadside tree. It is native to the Western Himalaya, Nepal. The forests along the upper Karnali river are dominated by *Alnus nitida*, which has not been recorded elsewhere in Nepal (Shrestha and Joshi, 1997). The trees prefer a sunny situation on moist soil. It has the properties like frost hardiness, fast growth and N₂ fixing. It grows well in moist situations on sandy soils. Especially this tree species is suited for farm forestry which is close to perennial streams.

Distribution range: W (1500 – 2800 m) native to the Himalaya and West Nepal and the forests along the upper Karnali River

Ecology: Along the riverline which prefer a sunny situation on moist soil.

Flowering: The male catkins bloom in September-October and the female flowers opening first, **Fruiting:** October–November.

Specimens examined: Western Nepal: *Humla*, Way down from Simikot, 2800m, 17 July 1968, S.B. Malla 14256 (KATH); *Mugu*, Thyarigaon, 2350 m, 9 Aug 1981, K.R. Rajbhandari and B. Roy 3646 (KATH); *Bajhang*, Dhuli, 2120 m, 25 July 1976, H. Tabata, K.R. Rajbhandari and K. Tsuchiya 1586 (KATH). (See Appendix 3)

Part II: Ecological Niche Modelling

3.1.1 Current distribution modelling

3.1.1.1 Spatial autocorrelation

Finally, the number of presence points of *A. nepalensis* was reduced from 112 to 67 and *A. nitida* from 14 to 12 (Table 3.1) from 10 min spatial grid to obtain least spatial autocorrelation (Fig. 3.1). These points were used for the further analysis in selection of predictive variables and model run.

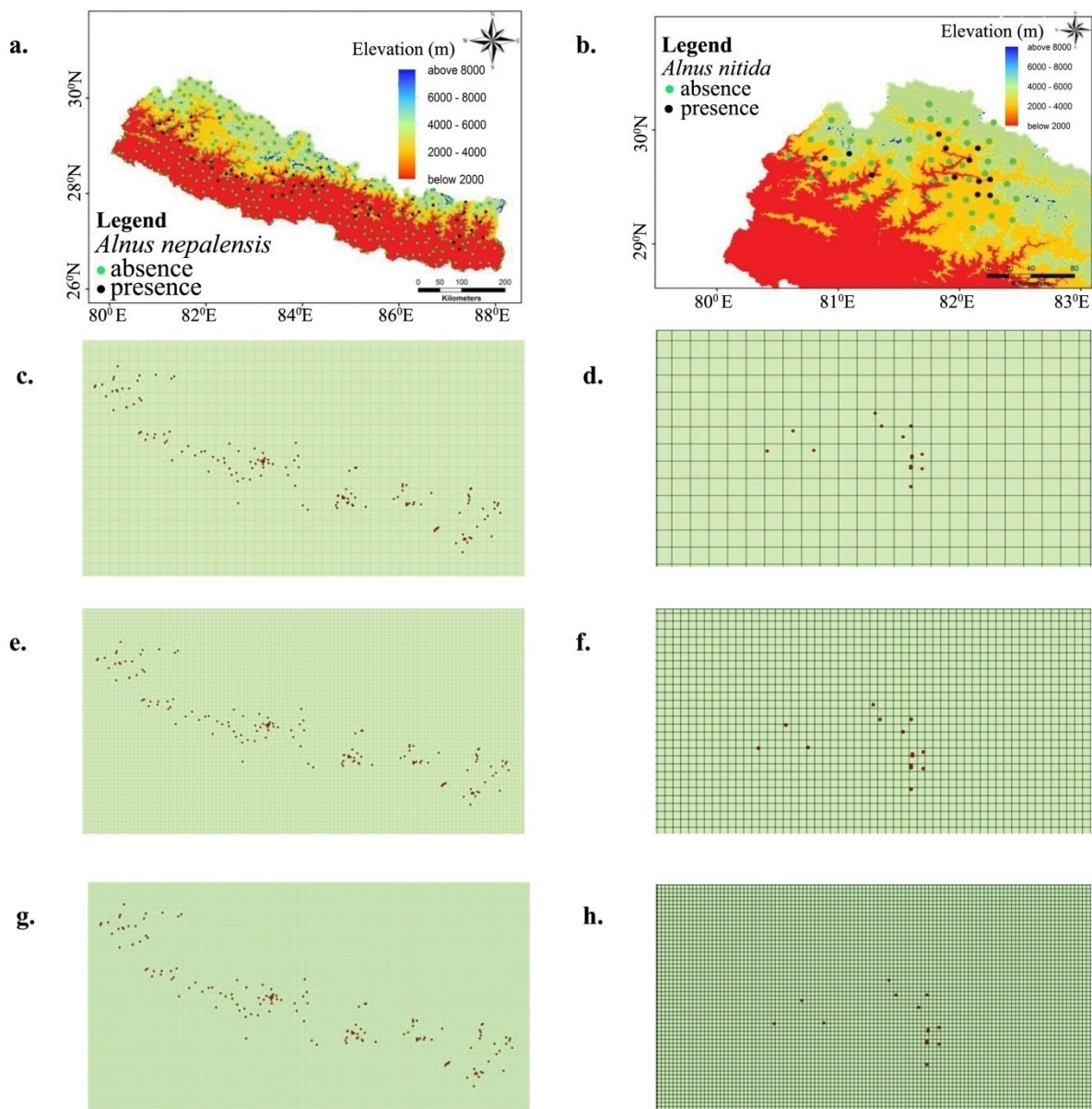


Fig. 3.1: Occurrence and background points used for bootstrapping and modelling of (a) *A. nepalensis* and (b) *A. nitida*; occurrence point location checked in spatial grid of different resolution (c) and (d) 10 minutes, (e) and (f) 4 minutes, (g) and (h) 2 minutes for *A. nepalensis* and *A. nitida* respectively.

Table 3.1 Number of duplicate records in specified grid.

	Total records	Duplicate records in		
		10 mins *	4 mins	2 mins
<i>A. nepalensis</i>	112	45	30	25
<i>A. nitida</i>	14	2	2	2

* Total number of species presence records within 10 minutes grids was used for modelling process.

The spatial autocorrelation performed using Moran's I for binary presence (1) and absence/pseudo-absence (0) data for two species of *Alnus* in the form of binary prediction indicates that the points were randomly distributed. The Moran's I value for both species are less than 1 but *A. nitida* has negative whereas *A. nepalensis* has positive value. The negative value of *A. nitida* indicates tendency towards dispersion and the positive value of *A. nepalensis* indicates tendency towards clustering (Table 3.2). But their Moran's I value is around zero which is negligible negative and positive. It indicates that the presence points are randomly distributed (Fig. 3.2).

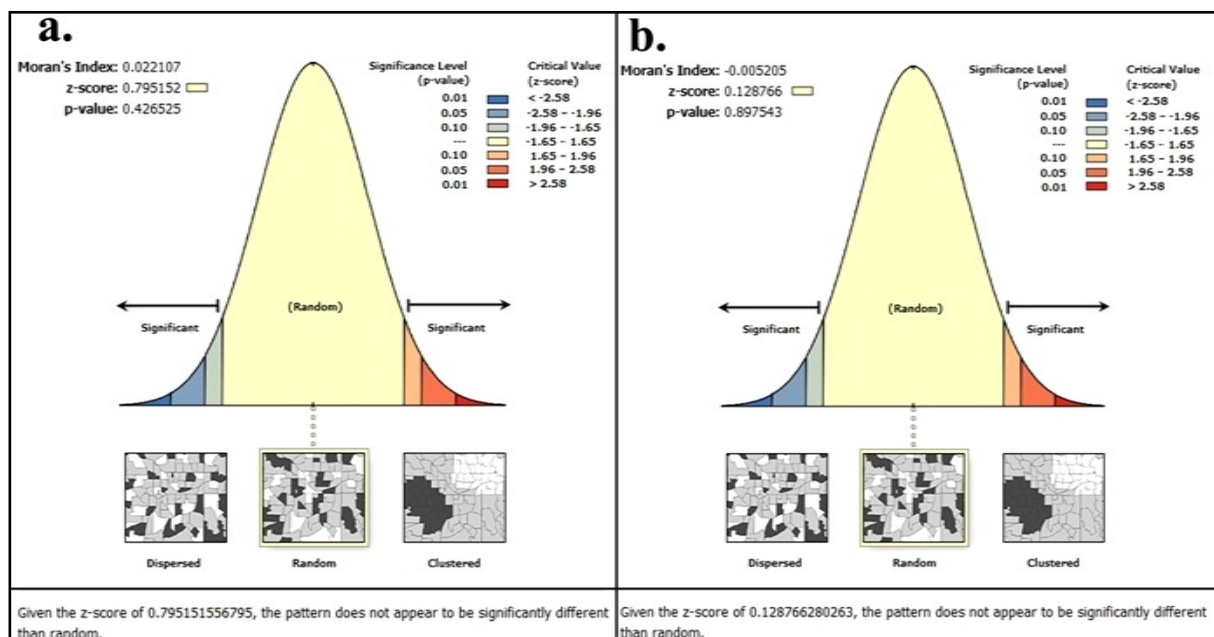


Fig. 3.2 Spatial Autocorrelation report for (a) *Alnus nepalensis* and (b) *Alnus nitida*.

The *P*-value is a probability. For the pattern analysis tools, it is the probability that the observed spatial pattern was created by some random process. When the *P*-value is greater than 0.05 (Table 3.2), it means it is very likely that the observed spatial pattern is the result of random processes. The pattern doesn't appear to be significantly different than random. This

indicates that the point is randomly distributed.

Table 3.2 Results of spatial autocorrelation test for two species.

	<i>A. nepalensis</i>	<i>A. nitida</i>
Moran's I	0.022107	-0.00521
p-value	>0.05 (0.426525)	> 0.05 (0.897543)

3.1.1.2 Normality test

The initial step to determine the significance of the models and to compare the means is to check if the results obtained from the 50 random models were normally distributed. This test further indicates to determine which test type to employ. Therefore, the Shapiro-wilk test was carried out in R-studio to determine if the results obtained were normally distributed. A *P-value* greater than 0.05 means the data is normally distributed. Table 3.3 shows the results for the normality test with all results greater than 0.05 except for the Test_AUC1 and Test_AUC4 of *A. nitida* which has value of 0.008 and 1.281×10^{-6} respectively.

Table 3.3 Results of the normality test for each species.

	Shapiro-wilk Statistics (<i>P-value</i>)		
	df	<i>A. nepalensis</i>	<i>A. nitida</i>
Training_AUC1	50	0.262	0.565
Test_AUC1	50	0.488	0.008
Training_AUC2	50	0.335	0.073
Test_AUC2	50	0.483	0.053
Training_AUC3	50	0.333	0.936
Test_AUC3	50	0.389	0.614
Training_AUC4	50	0.722	0.094
Test_AUC4	50	0.248	1.281×10^{-6}

Note: 1, 2, 3 and 4 represents Model 1, Model 2, Model 3 and Model 4 respectively for their corresponding training and test AUC data.

3.1.1.3 Threshold Independent Evaluation of the Models

Hypothesis 1. Testing the hypothesis that the models produced for each species are significantly better than a random model

H₀: AUC (train) and AUC (test) = 0.5

H₁: AUC (train) and AUC (test) >0.5

The results obtained by stepwise modelling as per Table 2.4 of the two species of *Alnus* are shown in Table 3.4. *P*-values calculated on average of Training AUC and Test AUC for all four models were found to be significantly better than a random model ($P < 0.00001$, using one sample T-test, 95% CI). The training AUC as well as Training gain increases for the models except model 3 for each species. It consistently increases from models with bioclimatic variables only through to models that include topographic variables and vegetation. However, Test AUC vary among two species with Test AUC of *A. nitida* decreasing consistently from model 1 to model 4 with an exception on model 4 (i.e. Test AUC = 0.8679). The Test AUC decreases from model 2 to model 4 except model 1 with lower Test AUC i.e. 0.7669 value than other model for *A. nepalensis*. In general the Training AUC and Test AUC for *A. nitida* is higher than that of *A. nepalensis*. Thus model 4 gives highest training gain and training AUC for both species. The t-test showed significant difference for all data partitions for average AUC.

Table 3.4 Results of threshold independent evaluation and *P*-values of average AUC.

Species	Model	Training AUC	Test AUC	Training gain	Test gain	<i>P</i> -values of Average AUC
<i>Alnus nepalensis</i>	1	0.830	0.767	0.613	0.515	$< 2.2e^{-16}$
	2	0.868	0.780	0.780	0.543	$< 2.2e^{-16}$
	3	0.840	0.773	0.679	0.536	$< 2.2e^{-16}$
	4	0.889	0.772	0.959	0.469	$< 2.2e^{-16}$
<i>Alnus nitida</i>	1	0.879	0.852	0.707	0.847	$< 2.2e^{-16}$
	2	0.908	0.842	0.840	0.830	$< 2.2e^{-16}$
	3	0.869	0.827	0.668	0.754	$< 2.2e^{-16}$
	4	0.946	0.868	1.197	1.146	$< 2.2e^{-16}$

From the test statistics produced against a null model of 0.5, it is concluded that the geographic distribution of *A. nepalensis* and *A. nitida* can be predicted using topographic variable and LULC along with bioclimatic variables to achieve both test and training AUC that are significantly better than a random model. Thus the Null hypothesis H_0 : as stated above is rejected and the alternative hypothesis H_1 as stated above is accepted.

Finally, model 4 gives the best prediction for both species of *Alnus*.

3.1.1.4 Sensitivity analysis

3.1.1.4.1 Jackknife test of Important variables

The jackknife test in MaxEnt was used to answer the question regarding which environmental variable is important for the potential distribution of *Alnus* species in Nepal. Average gains with and without each variable were calculated from 50 random distributions produced from each modelling. In the plots, the red bar indicates the overall performance of the model while blue bar shows the performance of the model with the only underlying environmental variables. The light blue bars on the other hand, indicate the performance of the model without the corresponding variables. In Fig. 3.3 of *Alnus nepalensis*, the environmental variable with highest gain when used in isolation is bio_9, which therefore appears to have the most useful information by itself. The environmental variable that decreases the gain the most when it is omitted is slope, which therefore appears to have the most information that isn't present in the other variables. Bio_6 happens to be the second most important variable with a clear drop in average gain when it is not in the full model. But in case of *Alnus nitida* Fig. 3.4, the environmental variable with highest gain when used in isolation is slope, which therefore appears to have the most useful information by itself. The environmental variable that decreases the gain the most when it is omitted is also slope, which therefore appears to have the most information that isn't present in the other variables. The second most variable which decreases the gain when it is not in full model is bio_18.

For the model of both species of *Alnus*, climate plays important role in determining the distribution of species whereas terrain roughness (t_rgh) seems to have less role in species distribution. Landuse Landcover type has the more gain in the model for *A. nitida* with decreased gain when it is not in used than *A. nepalensis*. Topographic variables as well as

bio_3, bio_4, bio_6 on their own achieve negligible MaxEnt gain and when they were removed from the model did not also decrease the overall gain significantly for *A. nitida* (see Fig. 3.3).

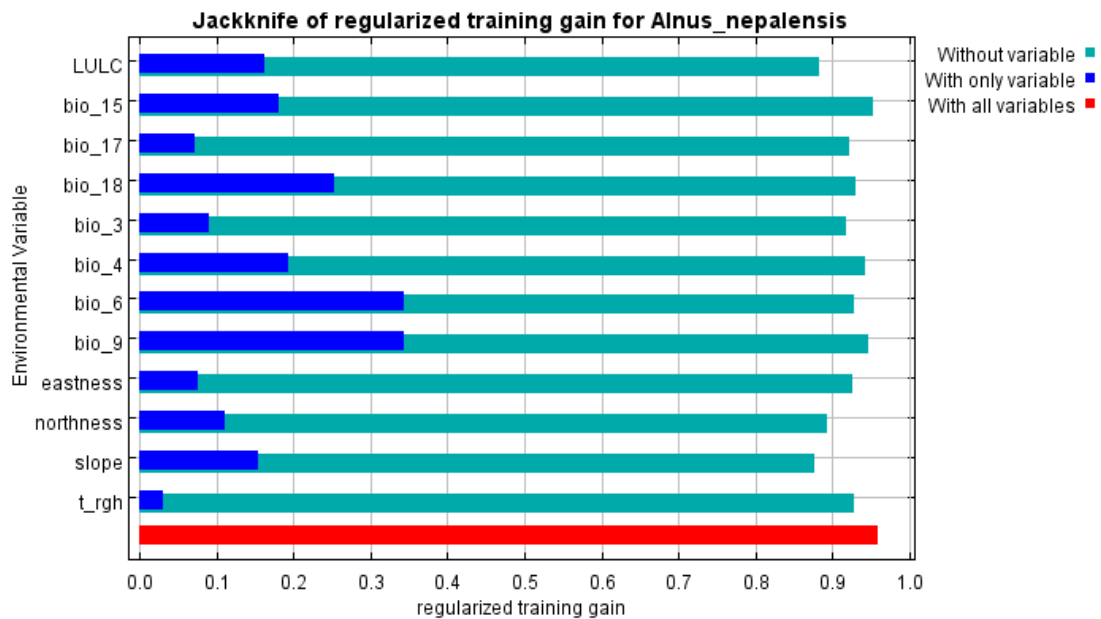


Fig. 3.3 Average regularized gains for each variable calculated from 50 subset models produced for *A. nepalensis* (Model 4).

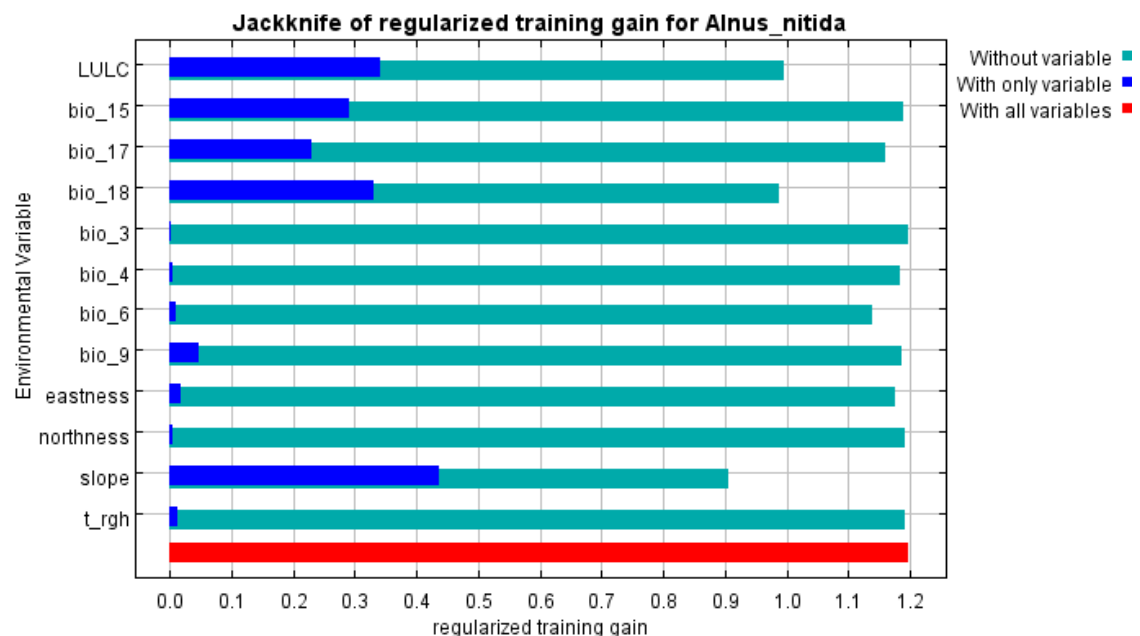


Fig. 3.4 Average regularized gains for each variable calculated from 50 subset models produced for *A. nitida* (Model 4).

3.1.1.4.2 Percent contribution of the variables

The percent contribution Fig.3.5 (see Appendix 5) estimated that, bio_18 and slope plays major role in determining suitable habitat for both *Alnus* species in the model. Similarly, LULC is equally responsible for both species in the model. Bio_3, bio_9 as well as terrain roughness has almost negligible contribution for *A.nitida*.

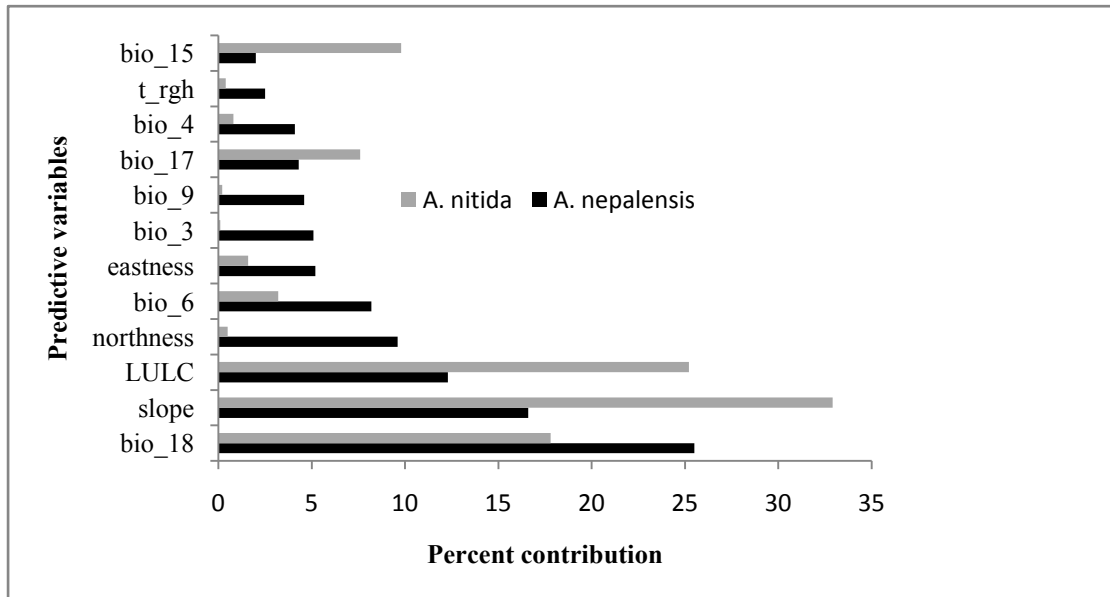


Fig. 3.5 Percent contribution for each variable calculated from 50 subset models produced for both species of *Alnus* (model4).

3.1.1.4.3 Response curves of the Predictor variables

The response curves show how each environmental variable affects the MaxEnt prediction. The curves show how the logistic prediction changes as each environmental variable is varied, keeping all other environmental variables at their average sample value. The Fig. 3.6 and Fig. 3.7 represents response curve for MaxEnt model created using only the corresponding variable of *A. nepalensis* and *A. nitida* respectively. These curves reflect the dependence of predicted suitability both on the selected variable and on dependencies induced by correlations between the selected variable and other variables. They may be easier to interpret if there are strong correlations between variables.

Results derived from curves showed that the probability of the presence of *A. nepalensis* increases with the increase in bio_3 (Isothermality), bio_18 (Precipitation of warmest quarter). Northness and bio_17 (Precipitation of driest quarter) increases the probability of presence. Negative to northness i.e. South indicates decreased probability of presence. The

eastness show tendency towards decrease in probability of presence but the negative value of Eastness i.e. West shows the increased probability of presence. Terrain roughness shows decreased probability of presence from 0.75 with more variation. Temperature seasonality (bio_4) decreases the presence probability. The increase in bio_6 (min. temperature of coldest month), bio_9 (mean temperature of driest quarter) and bio15 (Precipitation seasonality) increases upto 2.5, 1.1 and 1 respective unit respectively and finally decreases. LULC seems to have fluctuation in probability of presence with highest in category 22 i.e. urban areas. Slope of 13 – 18 degree have highest presence probability but then decreases and remains constant after 33 degree.

In case of *A. nitida*, increase in precipitation of driest quarter (bio_17) as well as terrain roughness shows increased probability of presence but terrain roughness has much more variation before and after value 1. The remaining variables like bio_3, bio_4, bio_6, bio_9, bio_15, bio_18, eastness, northness shows decreased probability of presence with increase in their corresponding value. Slope has the fluctuation of presence probability with highest at 23-27 degree but remains constant from 38 degree. Similarly LULC has same pattern as slope with highest at cat. 4 i.e tree cover, needle leaved evergreen, closed to open (> 15%) and remains absence in cat. 5 -10 (See Appendix 1).

The response curves for both species obtained as MaxEnt output is given below. In Fig. 3.6 and Fig. 3.7, the curves show the mean response of the 50 replicates Maxent runs (red) and the mean +/- one standard deviation i.e variation (blue, two shades for categorical variables).

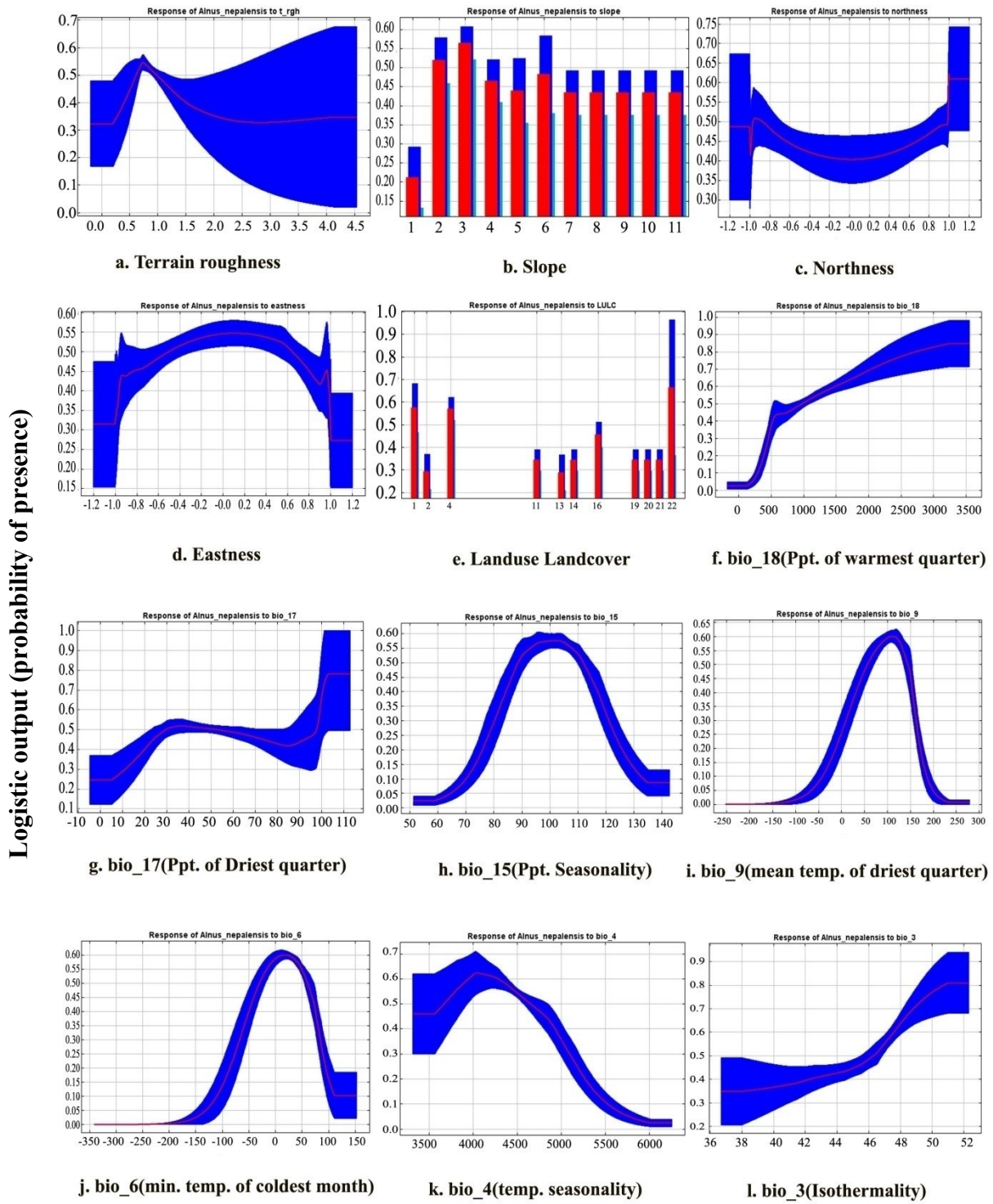


Fig. 3.6 Response curves of the predictor variables showing logistic output (probability of presence) for *A. nepalensis*. (Slope in degree, Temperature in $^{\circ}\text{C} \times 10$, precipitation in millimeters, terrain roughness in ratio)

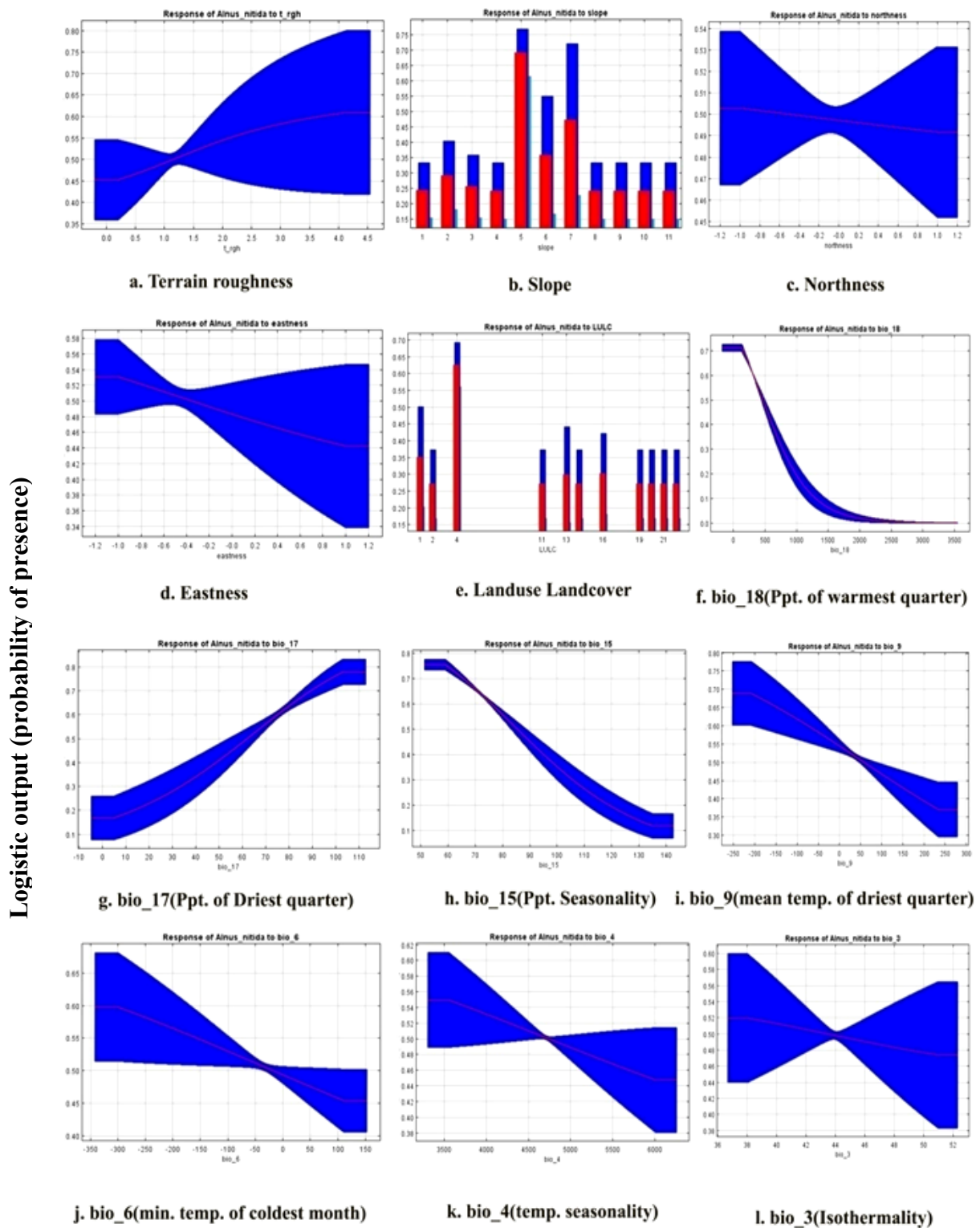


Fig. 3.7 Response curves of the predictor variables showing logistic output (probability of presence) for *A. nitida*. (Slope in degree, Temperature in $^{\circ}\text{C} \times 10$, precipitation in millimeters, terrain roughness in ratio)

3.1.1.5 Comparison of the means of the models

Hypothesis 2

$H_0: AUC_1 = AUC_2;$

$H_1: AUC_1 \neq AUC_2;$ where $AUC_1 =$ models with climatic variables and $AUC_2 =$ model that include topographic variables

Table 3.5 Results of the pair-wise mean comparison of the four models developed per species (*P-values shown*).

Species	Pair-wise mean comparison of the models						
		1,2	1,3	1,4	2,3	2,4	3,4
<i>A. nepalensis</i>	AUC _{tr}	< 2.2e ⁻¹⁶	0.00972	< 2.2e ⁻¹⁶	1.34e ⁻¹⁰	2.031e ⁻⁰⁷	< 2.2e ⁻¹⁶
	AUC _{ts}	0.1036	0.4834	0.5887	0.4298	0.3767	0.9033
<i>A. nitida</i>	AUC _{tr}	0.0001582	0.2648	< 2.2e ⁻¹⁶	6.10e ⁻⁰⁶	7.638e ⁻¹⁰	2.662e ⁻¹⁶
	AUC _{ts}	0.5357	0.09713	0.4209	0.3558	0.2317	0.05571

Note: AUC_{tr} = training AUC and AUC_{ts} = test AUC

Table 3.6 ANOVA table for training and test AUC of all four models for each species.

Species	df	F	P-value
<i>A. nepalensis</i>	3	19.03	7.1 e ⁻¹¹
<i>A. nitida</i>	3	12.3522	2 e ⁻⁰⁷

Analysis of Variance (ANOVA) was done to test if there is difference in the means of both the test and training AUC produced for each species under the four models (Table 3.6). The ANOVA result shows that there is significant difference in the means of AUC of all four models for *A. nepalensis* ($P < 0.05$) and *A. nitida* ($P < 0.05$). To further test which two means are significantly different, a pairwise comparison of the models was done (Table 3.5). The training AUC for all pairs of means of models produced for *A. nepalensis* were significantly different ($P < 0.05$) from each other. In case of *A. nitida*, pair of means of model 1, 3 did not show any significance for training AUC. Similarly, test AUC for all pairs of means of model also donot show any significance.

Contrary to the training AUC, a comparison of the means of the test AUC did not show any

significant difference for all model combination for *A. nepalensis*. The performance of each model is based on how well the model is able to predict the best data (Fielding and Bell, 1997). Therefore based on the pair wise comparison of the means of the models, it can be concluded that all four models have the same predictive power in terms of the test AUC for *A. nitida* (the test means were not significantly different from each other).

Gains produced from MaxEnt modelling have also been used in determining the best performing model (Yost *et al.*, 2008). Gains describe how well the model fits to the training and test dataset available. The average gains for all four models for both species of *Alnus* show that, model with climatic variables, topographic variables and Landuse landcover achieved the highest average training gains (Table 3.5 shows the training gains of *Alnus* species for all four models).

3.1.1.6 Model output for ecological niche

Finally model 4 was chosen which is significant for both the species of *Alnus*. The output of the model 4 was only presented for the ecological niche modelling of *A. nepalensis* and *A. nitida*.

The first model output is mean omission rate and predicted area plot averaged over the replicates run. The model calculated the omission rate for the training data. The average omission rate and predicted area as a function of the cumulative threshold for both the species of *Alnus* are presented in Fig. 3.8. The omission rate is the proportion of presence incorrectly predicted.

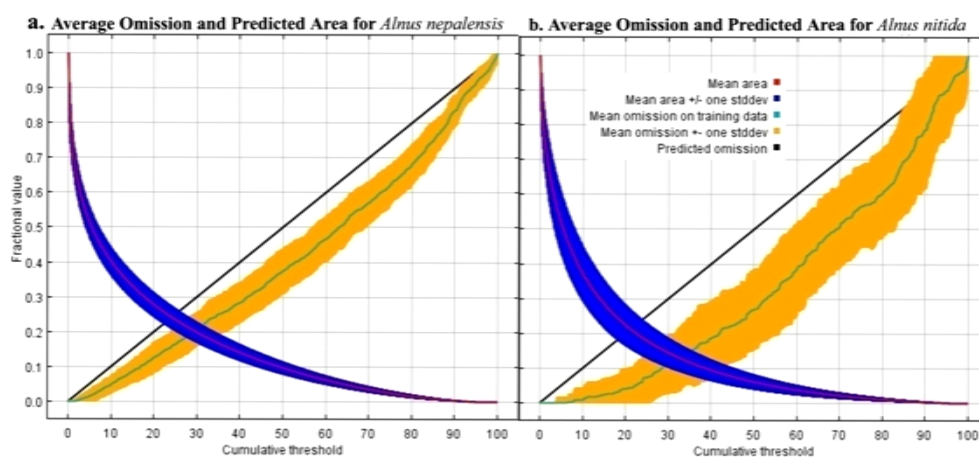


Fig. 3.8 Average omission rate for both the training and test data of (a) *Alnus nepalensis* and (b) *Alnus nitida* (the orange and blue shading surrounding the lines on the graph represent variation).

The Fig. 3.8 shows how mean omission and predicted area vary with the choice of cumulative threshold for *Alnus* species. For both species the mean omission on training data is less than predicted omission but *A. nitida* has more variation in the prediction than *A. nepalensis*. In case of *A. nepalensis*, the fractional value for predicted area is 0.2 at cumulative threshold 30 for mean omission on training data and for *A. nitida*, it is ~0.11 at cumulative threshold ~33 for mean omission on training data. The above mentioned fractional value represents that upto these value the probability of presence are incorrectly predicted.

The next output gives the Area Under the ROC curve (AUC) for the training data, averaged over the replicates run. The specificity is defined using predicted area, rather than true commission (Phillips *et al.*, 2006). The sensitivity measures the proportion of presence correctly predicted. The ROC curve for *A. nepalensis* and *A. nitida* are presented in Fig. 3.9.

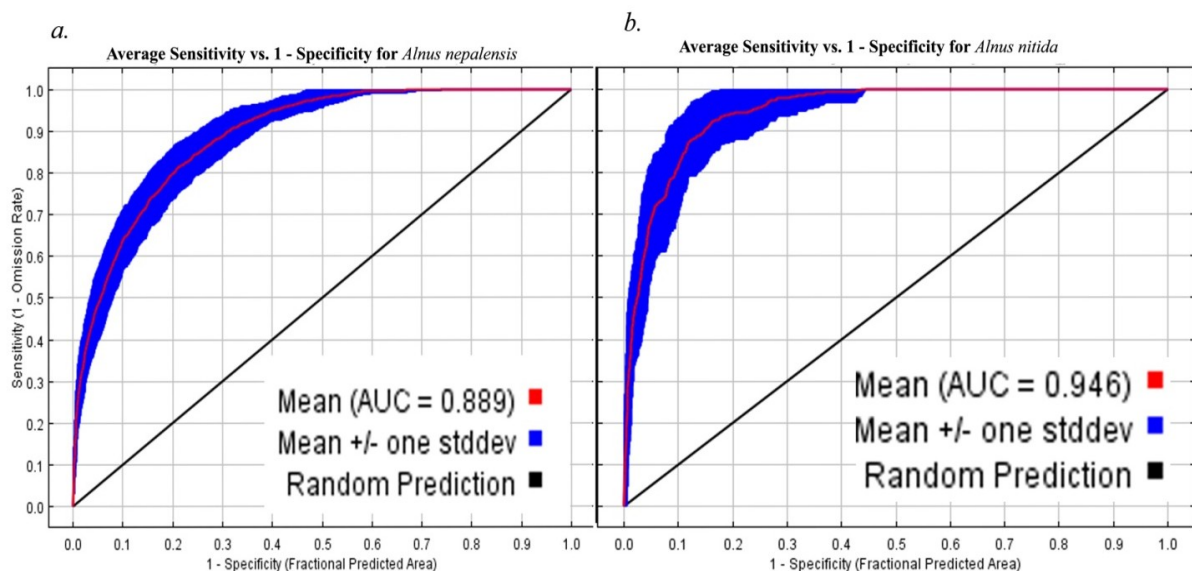


Fig. 3.9 The Receiver Operating Curve for training data for (a) *A. nepalensis* and (b) *Alnus nitida*

The above Area Under Receiver Operating Curve (ROC) for training data of both species indicates the validity and performance of model. An AUC value of 0.5 indicates that the performance of the model is no longer better than random, while values closer to 1 indicates better model performance. The Area Under the ROC (AUC) for *A. nepalensis* is 0.889 which indicates that the model 4 has 88.9% performance whereas *A. nitida* has 0.946 indicating the model has 94.6% performance. Comparatively model for *A. nitida* has high performance because this species has narrow ranges but *A. nepalensis* is widespread from east to west over the most area.

3.1.1.7 Current potential suitability of *Alnus* species

The MaxEnt model predicted potential region for *Alnus* species i.e. *A. nepalensis* and *A. nitida*. The model 4 (bioclimatic variable + topography + LULC) obtained for the present distribution of *A. nepalensis* and *A. nitida* performed well with an average AUC value of 0.889 and 0.946 respectively. The maps of potential distribution of two species are shown in Fig. 3.10a; b; c. These maps show potential distribution with their habitat suitability for two species. The maps are produced from the average of 50 random replicates of each species.

The Fig. 3.10a, showing the map of current suitability of *A. nepalensis* clearly depicts suitable area in most of the hilly and middle mountains. Some of the Siwalik ranges also possess suitable area. According to the model, the suitable area for *A. nepalensis* was predicted occupying covers 49381.6 km² in present climatic scenario (Table 3.7). The central region of Nepal contains the largest and most continuous area for the species whereas, the western region has dispersed distribution pattern. Furthermore, the area depicted for suitability has 19347.8 km² low suitability and 30033.9 km² high suitability which are more distributed in Western / lower hill and Central / Eastern / upper hill respectively (Fig. 3.10a). The several isolated patches of varying but relatively small size occurs in most of the western part and some in Siwalik range (Fig. 3.10a). The model predicts the Terai and High Mountain as the unsuitable area for *A. nepalensis*.

The Himalayan species *A. nitida* is widely distributed in Middle and High Mountain of Western region as well as in High Mountain in Central Nepal (Fig. 3.10b). Some patches of low suitability are found in Eastern and in Western Terai / Siwalik range. The total suitability area covers 16453.4 km² (Table 3.7). Comparatively, the western region is highly suitable for *A. nitida* covering an area of 13959.3 km² whereas low suitability area has an area of 2494.03 km² (Table 3.7). The Fig.3.10b depicts that Trans-himalaya area are the potential suitability area for *A. nitida*. These suitability areas are predicted more within the extent of Himalaya. Mostly Karnali and Dhaulagiri region highly predominates the species *A. nitida*. The lower high mountains of central region are potentially a novel location for *A. nitida*, as there are no official reports or collection of the species from the area. The model also predicts some ecotones in eastern hilly region as novel places that lacks the collections or records.

The model predicts clear demarcation for two species. The spatial extent affected the distribution of two species. The Himalayas are considered as the barrier that separate most of the *A. nitida* from *A. nepalensis*. The other patches of suitability region might be the

overprediction of the MaxEnt model or as a novel places (Fig.3.10c). The climatic spaces for both species were along the river valley. The river valleys play significant role in distribution of these two species. The model predicted relative likelihoods of the habitat suitability for *A. nitida*, North-West to Annapurna and Dhaulagiri range whereas, South-East for *A. nepalensis* extending upto Siwalik range (Fig. 3.10c). From Table 3.7, it is clear that only 1764.07 km² of the area is suitable for both the species. In case of *A. nitida* only, 14689.33 km² is the suitable area whereas, 47617.6 km² is for *A. nepalensis*. The suitable predicted area region is mostly concentrated above 1,500 m a.s.l. (Fig. 3.10c).

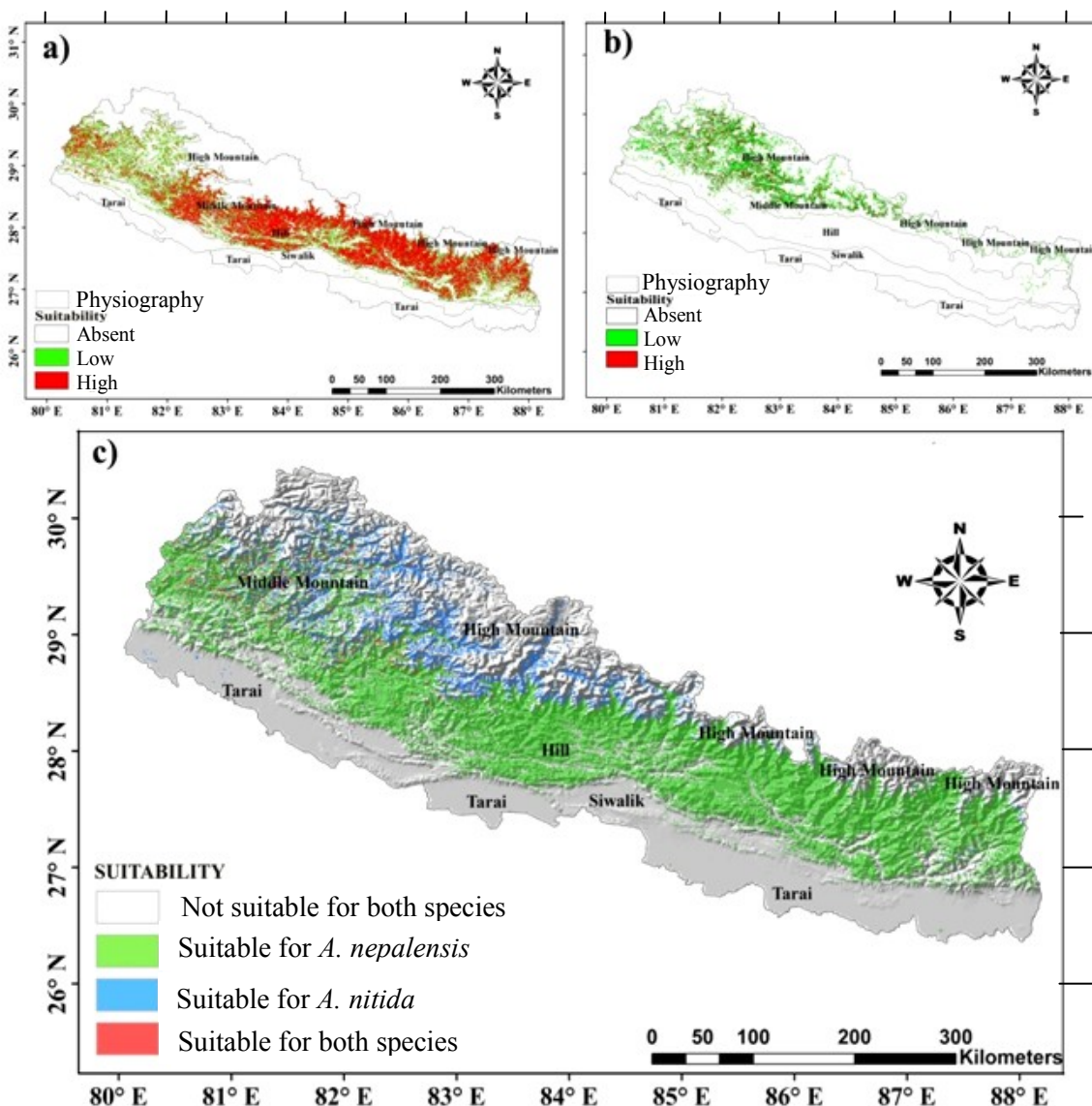


Fig. 3.10 Current potential suitability maps showing potential distributions in Nepal: (a) *A. nepalensis*, (b) *A. nitida* and (c) *Alnus* species combinely.

3.1.2 Future potential suitability of *Alnus* species

The future potential suitability of the model 4 was based on the IPCC SRES-A1B Scenario for 2050. The visual observations indicate that under the assumption of model 4, current potential distribution for *Alnus* species changes much in future. The changes in area of potential suitability vary among two species.

Fig. 3.11 a; b, indicates that *A. nepalensis* has the similar distribution pattern as that of current distribution. These species are widely distributed in Middle mountains. The suitability shifts towards the North-West towards high mountains. South of high mountains is the potential area for the *A. nepalensis*. The considerable decrease in the *A. nepalensis* is seen in Central Development Region followed by Eastern and Far western Development region (Fig.3.11a; b). The suitability level increases on going towards Northern Himalayas but lowest in high mountains due to mountainous barriers. There is loss of 8.41% area in 2050 under IPCC SRES-A1B Scenario (Table 3.7). This loss in area covers 12379 km². In case of *A. nepalensis*, the total suitability area decreases from 47617.6 km² to 30894.7 km², which accounts for loss of 11.36% suitable area for distribution or plantation. Similarly, *A. nitida* for 2050 also shows the same pattern of distribution as current potential distribution (Fig.3.11c; d). The western part of middle mountains are the projected region for *A. nitida* with their suitability value 0.89 (Fig. 3.11d). Those potential areas are predicted towards North-West of Annapurna and Dhaulagiri range. *A. nitida* are western Himalayan trees so, other region like western Siwalik- Terai and some patches of Eastern Hill-Siwalik are either the novel places for 2050. The suitable area for *A. nitida* increases to 17392 Km² in 2050 by 938.63 km² from current suitable area lying highly suitable area in Middle Mountain (Table 3.7). This increase in area by 0.64% is slightly towards South- East. But the Fig.3.12b shows that the increase in area is discontinuous towards South-East. If we consider only *A. nitida* forest, then the forest reduces by 2.32% from current suitable area in future 2050 (Table 3.5). On overlaying the two layers of *Alnus* species for 2050, the potential suitable area is found to be the Middle Mountain of Western region (Fig. 3.11e). The region covers an area of 6107.64 km² (4.15%) which is more than current potential by 2.95%.

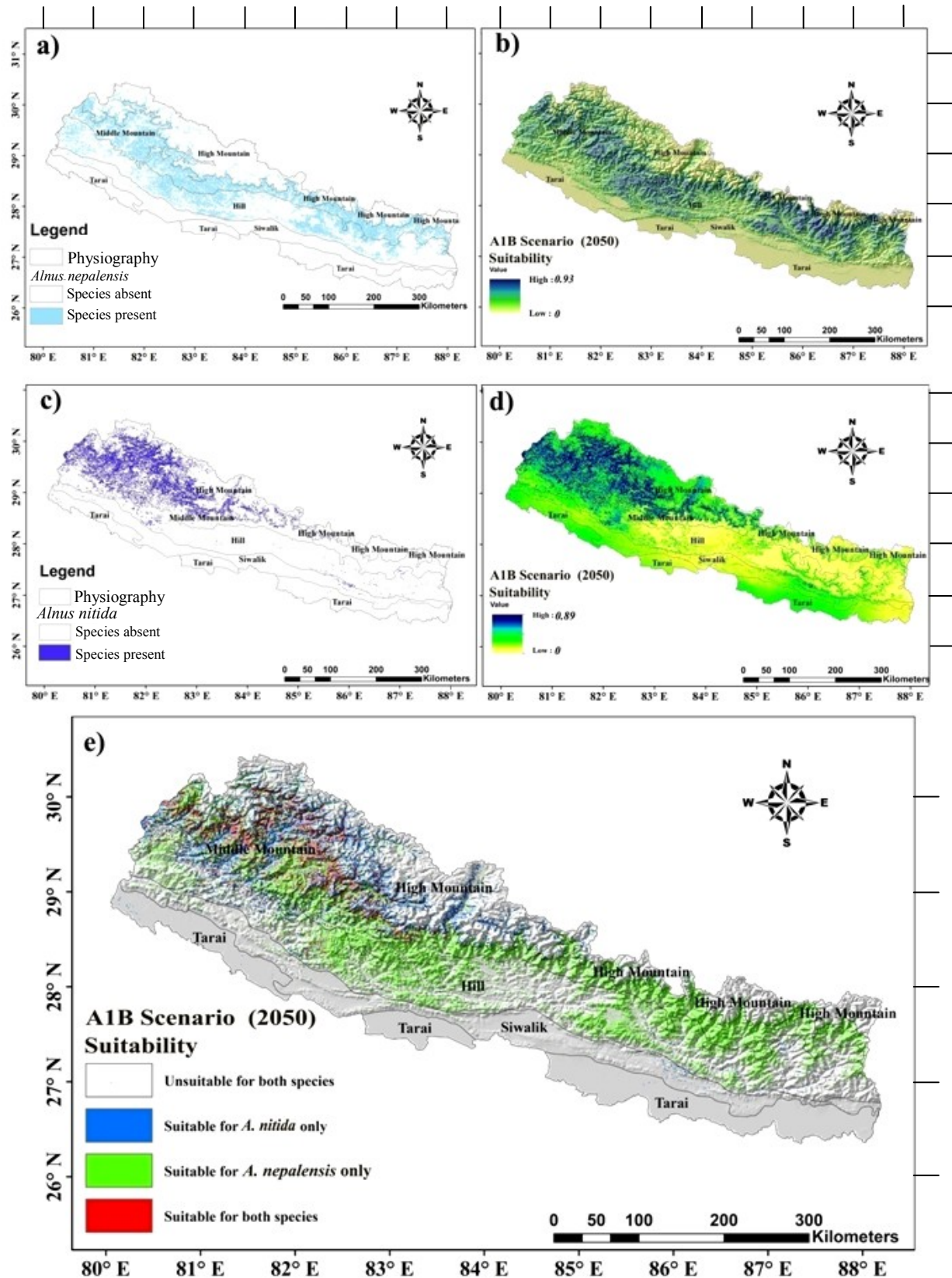


Fig. 3.11 Potential suitability maps of *A. nepalensis* for SRES-A1B Scenario 2050 in Nepal: (a) and (c) Suitable and species absent region for *A. nepalensis* and *A. nitida* respectively, (b) and (d) Suitability value for *A. nepalensis* and *A. nitida* respectively, and (e) *Alnus* species combinely.

Table 3.7 Predicted distribution area (km² and %) for *Alnus* species in Nepal as per current and future SRES-A1B Scenario 2050 along with their gain or loss. (Note that the area calculated is the suitability projection but not the actual occupying area)

Species	Suitability category	Current area	Future scenario area	Gain/Loss (km ²)	Gain/Loss (%)
		km ²	km ²		
<i>A. nepalensis</i>	Low	19347.79			
	High	30033.85			
	suitable (total)	49381.64	37002.35	-12379.3	-8.41
<i>A. nitida</i>	Low	2494.03			
	High	13959.33			
	suitable (total)	16453.36	17391.99	938.63	0.64
Combined	<i>A. nitida</i> only	14689.33	11284.35	-3404.98	-2.31
	<i>A. nepalensis</i> only	47617.57	30894.71	-16722.9	-11.36
Combined	Both*	1764.07	6107.64	4343.57	2.95

*Area suitable for both species

3.1.3 Stability of the species potential distribution range under climate change

The major fraction of the projection representing the current distribution of the *Alnus* species can be considered as a stable area for IPCC SRES-A1B 2050 period (as projected by models). According to the model only 17.82% and 6.43 % of the current suitable area can be considered as stable over time 2050 for *A. nepalensis* and *A. nitida* respectively (Table 3.8). Comparatively, there is less expansion than reduction in suitable area from current to 2050 (Table 3.6, Fig. 3.12a and b).

The Fig.3.12a and Table 3.8 obtained from the model predicts that reduction suitable climatic space for *A. nepalensis* is more than that of expansion in 2050, while stable space was found comparatively higher than change in climatic space. In future the North West shifts forest of *A. nepalensis* (Fig. 3.12a) covers an area of 10780.8 km² whereas southern part hilly region loses an area of 23160.1 km².

The SRES-A1B scenario for 2050 predicts 9468.69 km² as the stable area and loses 7923.3 km² suitable areas from the current area. This reduction in *A. nitida* forest is more than expansion. About 990.22 km² of the *A. nitida* forest gets expand in 2050 towards Eastern Himalaya but in discontinuous manner (Table 3.8, Fig. 3.12b).

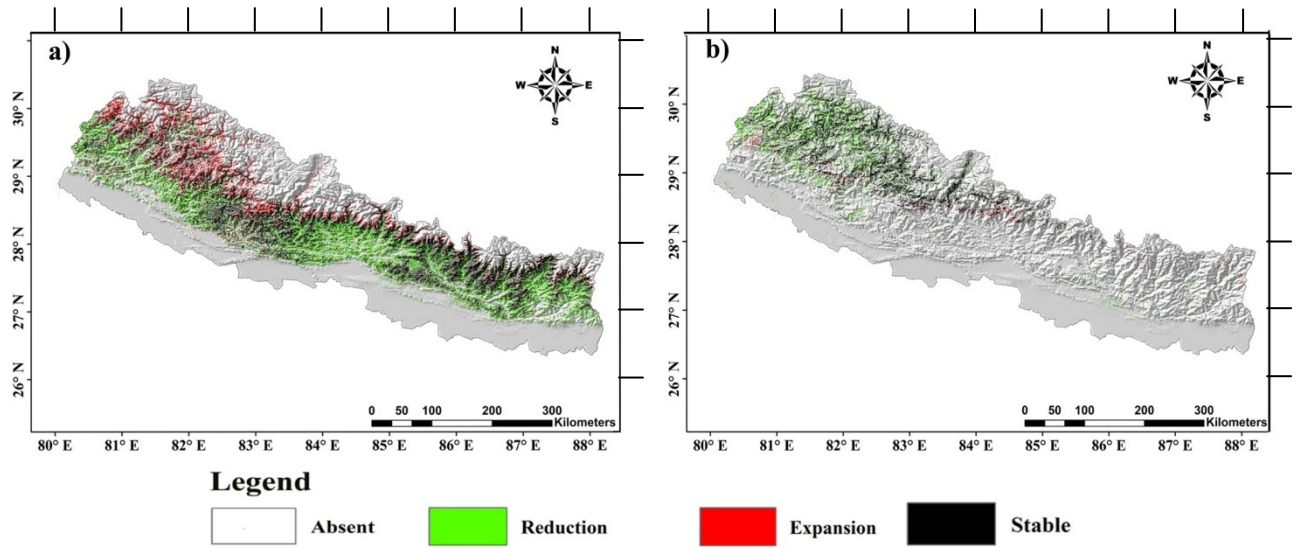


Fig. 3.12 Potential suitable maps showing geographic distribution from present to future SRES-A1B scenario 2050 in Nepal: (a) *A. nepalensis*, and (b) *A. nitida*.

Table 3.8 Change in suitable area for focal species based on comparison of ENM of the species in baseline (current) and future (2050) climate scenarios.

Species	Unchanged		Suitable area gained in 2050		Area lost in 2050	
	km ²	%	km ²	%	km ²	%
<i>A. nepalensis</i>	26221.6	17.82	10780.8	7.32	23160.1	15.74
<i>A. nitida</i>	9468.69	6.43	990.22	0.67	7923.3	5.38

3.1.4 Analysis of extent of extrapolation using multivariate environmental similarity surfaces (MESS) analysis.

Fig. 3.13a shows the extrapolated region of *Alnus* species obtained from the MESS (Multivariate Environmental Similarity Surface) analysis. The MESS score ranges from -59.7403 to 49.9652 which is average over 50 replicates. The negative values indicate extrapolated areas which are mostly throughout Terai region from east to west (Fig. 3.13a). The greater negative MESS values in Terai region indicates points lies outside the training range, whereas positive MESS value in hilly area indicates locations within the training range (Rodder *et al.*, 2013). Some patches of area are found in high hill and central hilly region. The model extrapolates most in those aforementioned areas and these extrapolation are more influenced by bio_6 (Fig. 3.13b). Some of the extrapolated region are by bio_15 in Upper Dolpa, by bio_3 in Solukhumbu and eastern India boarder in Siwalik range and bio_4 in

Dang (Siwalik range), Western Indian boarder. The MoD score has the highest value of 0.115134 mostly in Western, central and Eastern Terai. The extrapolation is mostly along the river system like Bagmati river basin, Gandaki river basin, Tamor, Saptakoshi, Dudhkoshi, Sunkoshi, Karnali (Fig. 3.13b). The extrapolation for *A. nitida* shows similarity with *A. nepalensis* because of the same training range used for the modelling as well as the same bioclimatic variables.

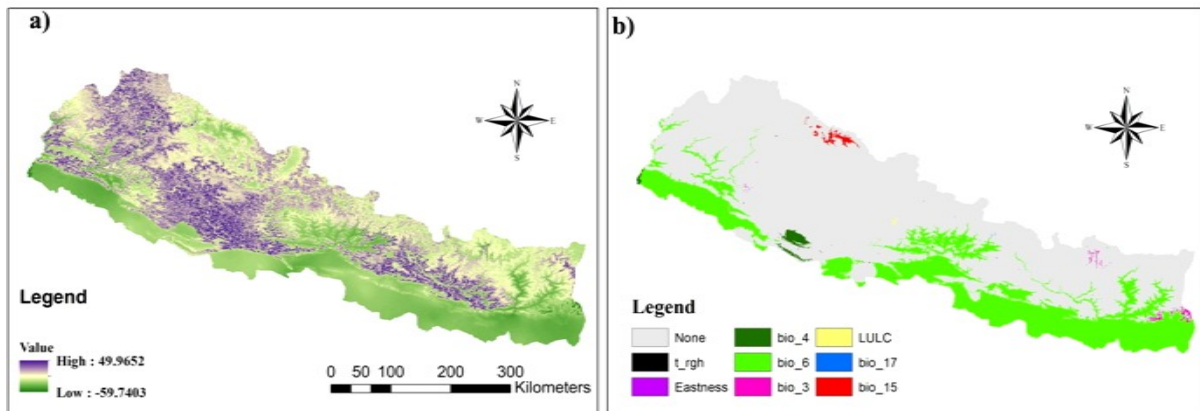


Fig. 3.13 (a) Map showing extrapolation region of *Alnus* species for SRES-A1B Scenario 2050 using MESS analysis, and (b) Clamping map of *Alnus* species for SRES-A1B Scenario 2050 using MOD analysis.

3.2 Discussion

The present study relates climate change, LULC and changes in the potential niche altogether to model the climatic suitability of the focal species.

Morphologically, the focal species differ in terms of their height and leaf characters. *A. nepalensis* are ca. 20 m tall trees with their robust leaf petiole of 1-2 cm long and upto 16 cm long male flower whereas *A. nitida* are ca. 10 m tall trees with their glabrous leaf petiole of 2-4 cm long and upto 14 cm long male flower. These characters are also used as diagnostic characters for identifying the focal species in Flora of Pakistan (1975), Flora of China (1999) and Flora Simlensis (1902) too.

This section discusses the results relating it to quality of data used in the modelling, ecological significance of the output of the modelling and how the results could be improved in future work. The brief discussion for the modelling is presented below:

3.2.1 Performance of the modelling procedure

A growing field in ecology is that of modelling ecological niche for prediction of geographic distribution of species (Scott *et al.*, 2002). These models allow the analysis of biodiversity phenomena, including geographic distribution, future potential distribution under climate change scenario (Thomas *et al.*, 2004). In recent years, there is extensive growth of use of modelling approaches based on occurrences of species and feature of the ecological and environmental landscape (Guisan and Zimmerman, 2000; Pearson and Dawson, 2003; Soberon and Peterson, 2004). The distributional model used in the current study is not just to understand the species ecological requirements but also to understand aspects of biogeography of *Alnus* species in Nepal. The species distribution modelling is widely used in the region where there are least known occurrences of species (Guisan *et al.*, 2006; Ranjitkar *et al.*, 2014a; Zhang *et al.*, 2012).

Ecological niche modelling proponents are using distributional information to estimate the ecological niches and potential distribution of species, which provides a means of understanding and anticipating ecological and geographic features of species distributional biology (Soberon and Peterson, 2005). The uncertainties and limitation in SDM techniques leads to under or over predict the species distribution (Barry and Elith, 2006; Ranjitkar *et al.*, 2014a) and certainly creates obstacle to generate accurate models. So to predict the niche of *Alnus* tree I focused on the machine learning MaxEnt which estimates the species distribution probability by assessing the maximum entropy distribution. MaxEnt works solely on presence only data. It combines presence only data with ecological layers to create species distribution model using a statistical method. The pseudo-absence or background data yield the predictive distribution model (Engler *et al.*, 2004; Barbet-Massin *et al.*, 2012; Ranjitkar *et al.*, 2014a). The background points were selected randomly to calibrate model. While gathering presence only data, spatial autocorrelation could have impact on SDM (Ranjitkar *et al.*, 2014a). The spatially correlated points lead to predict the same habitat. The multiple observation within the confined geographic area could be spatially correlated which is exemplified by *A. nitida* in Mugu-Humla region. The more important is that when selecting background points within the extent of Nepal for geographically restricted species, the spatial autocorrelation should be prevented. The uncertainties behind MaxEnt is that it over predicts. We should consider that the focal species are just predicted but not real.

A. nitida, which is geographically localized to western Himalaya region and fragmented

habitat species results in the clustered distribution. Such kind of habitat is common to *Alnus* tree. So I checked the presence points in different spatial grids to reduce the number of occurrence points to minimum requirements of SDM (Ranjitkar *et al.*, 2014a). Spatial grid of 10 minute generally reduces the spatially correlated points. Finally, selecting random points in each 10 minute grid, the clustered points changed to randomly distributed points resulting in the reduced spatial autocorrelation. This is verified by the Moran's I value that calculates spatial autocorrelation for presence points and randomly selected background points around presence points. Further the ecological niche of focal species was forecasted using the least correlated points along with their prediction along with their biologically predictive climatic variables.

3.2.2 Influence of environmental predictor variables for *Alnus* tree

The niche of *Alnus* species has been analyzed considering all the predictive environmental factors. The predictor environmental variables were grouped into 3 major groups namely, bioclimatic, topographic and LULC. The influences of environmental variables were analyzed by MaxEnt Jackknife test, percent contribution and response curves.

3.2.3 Effects of topographic variables

The percent contribution of the variable and jackknife test diagnosed their contribution and regularized training gain respectively to the model for prediction whereas response curve predict the probability of presence. The three test analyzed that slope has more significant role in determining suitability of *Alnus* species. The percent contribution and regularized training gain of the slope indicates that *A. nitida* is more influenced than that of *A. nepalensis*. *A. nitida* generally need more slopy land as compared to *A. nepalensis*. So, *A. nitida* are likely to occur in high Himalaya where there is less precipitation. But less slopy land are sufficient for *A. nepalensis* to grow. Generally steeper and fragile lands are necessary for *Alnus* species to grow (Sharma *et al.*, 1998; Sharma and Sharma, 1997). The next variable Aspect i.e. Northness and Eastness is found to be deterministic for species to distribute. The North-Western region predicted as suitable region for *Alnus* species is in consistence with that of Sheikh (1993) and Sharma *et al.* (1998) who noted the distribution of *Alnus* species. There is wide variation in the distribution of *A. nitida* in Northern-Southern as well as Eastern region. These varied regions are the extrapolation region of MaxEnt output. Terrain roughness is found to have less gain and contribution but result from response curve suggest

that rugged terrain land for *A. nitida* is suitable with wide variation. As compared to *A. nitida*, *A. nepalensis* can even grow in moist and well-drained soils, including loam and loamy sand gravel, sand and clay.

3.2.4 Importance of landuse landcover

It was predicted that the inclusion of the LULC in the modelling could improve the model performance and results in better estimation of the potential distribution of the *Alnus* species. The habitats composed of spatially heterogeneous abiotic conditions provide a great diversity of suitable niche for plant species (Elith and Leathwick, 2009). LULC plays important in determination of species niche (Sala *et al.*, 2000). Nepal's natural vegetation has been transformed from dense vegetation cover to more and more managed ecosystem. These changes are associated with the process of removing trees from the area of land, loss in biodiversity and reduction in land. Urban areas and broadleaved deciduous tree cover are the main ecosystem where *A. nepalensis* occur. But, *A. nitida* are geographically restricted to needle leaved evergreen tree cover area of western region. The probability of presence changes on changing LULC type. The result indicates that as tree vegetation is lost, the *Alnus* species also decrease their occurrences. Mostly, *A. nitida* is influenced by urban areas. These urban areas are the probable site for the plantation. In agroforestry system, *A. nepalensis* are planted along the urban areas of hilly region. As per the model results, it was observed the decreasing shift of distribution from forest type to non forest type.

3.2.5 Response to climatic variables

Distributions of plants are broadly influenced by their physiological tolerance to climatic factors (Woodward, 1992). The jackknife test from MaxEnt, percent contribution and response curve has different predictive power. For both *Alnus* species precipitation of warmest quarter has more contribution in the prediction. Probability of *A. nepalensis* increases with the increase in bio_18 (Precipitation of warmest quarter) with optimum rainfall about 1000mm. But Probability of *A. nitida* increases with the increase in bio_17 (Precipitation of driest quarter) with optimum rainfall about 70mm. Probably, *A. nepalensis* found in wetter part of Himalayas require more rainfall than *A. nitida* found in drier western Himalayas therefore rainfall during warmer part and drier part of the year is one of determining factor for habitat suitability of *A. nepalensis* and *A. nitida* respectively. Till now there was no study for investigating the relative importance of temperature and precipitation

to determine the niche of *Alnus* species. One possible interpretation is that considering the variables both temperature and precipitation are important factor in climate change, the result suggest that temperature have more considerable negative influence than precipitation for *A. nepalensis* distribution with an exception that Isothermality increases the distribution. But, for *A. nitida* only precipitation of driest quarter has positive influence whereas remaining temperature as well as precipitation has negative influence. The suitable niche for *Alnus* species is more characterized by precipitation which ranges from less than 150 mm to more than 5600mm (Sakalli, 2013). The bioclimatic variable that delimit niche of *A. nepalensis* is warmest quarter whereas driest quarter for *A. nitida*.

3.2.6 Inference from the model

3.2.6.1 Threshold independent evaluation

The potential distribution model for *Alnus* species seems to agree quite well with the sample points. The training and test AUC for all models are normal except for Test AUC1 and Test AUC4 for *A. nitida*. All four models produced for *Alnus* species consistently predicted potential distribution better than random. The most reliable fact is that a reasonably high AUC (see Table 3.2) was achieved for a model that includes climatic variable, topography and LULC for both species. In terms of significance the results show better than random prediction for all models ($p < 0.00001$, one tailed T-test, 95% CI). According to Phillips *et al.* (2006), a perfect model should contain a set of environmental variables that sufficiently describes all the parameters of the species fundamental niche relevant to its distribution. Therefore even though the model with climatic variable and topography predict more than the model with climatic variable and LULC in terms of performance, it is difficult to say that the output of the model predicts full range of niche than that of model 4 for *Alnus* species. *A. nitida* are localized in small area so its performance in terms of AUC as well as gain is more than widely distributed *A. nepalensis*. The main aim for modelling in a stepwise manner as done with the range of environmental variables was to identify how AUC changes in addition with each environmental variable. These procedure estimates the impact of the environmental variables. The average AUC achieved for *A. nepalensis* is lower than *A. nitida*. This is best explained by the fact that ROC/AUC is usually affected by the type of species under study and its range of distribution either narrow or wide. For presence only modelling, the maximum AUC is less than 1 (Phillips *et al.*, 2006). It must be emphasized that *A. nepalensis*

is a wide ranging species which occupy wide geographic areas and lives under greater environmental space than *A. nitida*. The AUC result should be interpreted with caution because of the behavior of the ROC/AUC when applied to presence only model (Anderson *et al.*, 2003). Lobo *et al.* (2008) noted that AUC represent the likelihood that presence will have higher predicted value than an absence regardless of the goodness-of-fit of predictions. So there is chances that overestimate or underestimate of all the prediction will have good AUC value in poorly fitted model and vice-versa in case where probabilities of presences are moderately high than those for absences. So, due to these uncertainties with use of AUC, the models were evaluated sometimes by average training gain obtained from MaxEnt. So the result also suggests that the average training gain over 50 subsets shows a significant improvement over model 4 for focal species. This gain determines the power of environmental variables on the model.

3.2.6.2 Threshold dependent evaluation

The choice of thresholds has significant impacts on the results expected from species distribution models especially if the results are used to identify the change in potential distribution under climate change. The threshold adopted will also have profound effect on the accuracy of the models based on the extrinsic test omission rate and fractional predicted area calculated by MaxEnt. Anderson *et al.* (2003) noted that a low omission rate is necessary but it is insufficient for a good model. Thus the threshold should be chosen with species ecology and reality within the study area. The optimal threshold for the application in binary maps such as those used in determining range shift is still unresolved for species distribution circles (Anderson *et al.*, 2003; Liu *et al.*, 2005; Phillips *et al.*, 2006). The MaxEnt predictive ability also determines the right choice of thresholds. In case of the overpredicted picture of focal species distribution, threshold that maximizes sensitivity and specificity of the test point is chosen. *A. nitida* is selective in its habitat in the western Himalayan region along the Mugu-Karnali river. So it might have low AUC. Results of fractional predicted area for *A. nepalensis* is more than that of *A. nitida* because of wide geographic range of species. The increased fractional predicted area has higher fraction of area predicted as suitable niche.

3.2.7 Climatic space and distributional pattern for *Alnus* tree

Potential niche for *Alnus* tree in Nepal has been predicted by MaxEnt. It predicts the distribution and climatic space for *Alnus* tree based on presence records. The climatic

variables, topographic variables and LULC are considered to be the important factor that delimit the climatic space and project the distributional pattern of *Alnus* tree. The current pattern is based on bioclimatic variables from 1950 – 2000 A.D. whereas the future pattern is studied based on IPCC SRES-A1B scenario of 2050.

3.2.7.1 Current potential suitability of *Alnus* species (1950 – 2000)

The MaxEnt predicts Alder species North of Siwalik from East to West extending upto Middle mountains. Central and eastern region are dominated by native species *A. nepalensis*. The western Himalaya associates *A. nepalensis* with *A. nitida*. The North-Western region is predominated by *A. nitida*. Thus *A. nepalensis* has wide range of distribution throughout Nepal whereas *A. nitida* are localized in small geographic region. The field surveys and published studies have shown that *Alnus* tree occurs above Siwalik range upto High Mountains mostly in the evergreen, broadleaved forest. The symbiotic association with other plants or its N₂-fixing ability enhances the wide distribution of the species. The mountainous and the river valley clearly separate the potential geographic region of *Alnus* species. Our model predicted the Trans-Himalayan region of Western Nepal to be the suitable region for *A. nitida*. Most of the flooded and undisturbed lands are the occurrence region for *A. nepalensis* (Sharma *et al.*, 1998) whereas sandy and moist river banks are for *A. nitida* (Singh *et al.*, 2010). The climatically suitable region might not have distribution of species. They are limited by edaphic and biogeographic factors (Ranjitkar *et al.*, 2014b). The actual distribution are prone to limited by seed dispersal mechanism, colonization capacity and LULC change (Sexton *et al.*, 2009; Ranjitkar *et al.*, 2014b). Comparatively very less area is occupied by *A. nitida*. Those projected area might not represent actual occupying area.

Those suitability areas are the required niche for the *Alnus* species. The important delimiting factor for its niche is climatic variables. Aspects i.e. Northness and Southness, Slope and LULC have also contribution for its niche determination. Besides all these variables *Alnus* tree are responsive to precipitation and temperature. These climatic factors are essential for species occurrence when modelling is carried out in large geographical area (Pearson and Dawson, 2003; Ranjitkar *et al.*, 2014b).

Our model diagnosed strong response to precipitation of warmest quarter, slope and LULC type. Precipitation of 100 mm in the driest period has the highest probability of presence for both *Alnus* species. Beside precipitation our model diagnosed minimum temperature of

coldest month to have more contribution for *Alnus* species.

The niche of *A. nepalensis* is also determined by Isothermality (bio_3) and precipitation of driest quarter. But increase in temperature seasonality is unsuitable for its presence in certain niche area. The suitability decreases when there is decrease in mean temperature of driest quarter from 10⁰C, precipitation seasonality from 100 mm and minimum temperature of coldest month from 2⁰C.

The niche of *A. nitida* is characterized by precipitation of driest quarter. The less precipitation of western drier parts and minimum temperature either in term of Isothermality or Seasonality, possess the suitable niche of Western Himalayan Alder. Similar niche have been noted by several literature for *A. nitida*. These species are usually found on dry, sandy soils (Sheikh, 1993). The model predicted that, with regard to climatic space, the sub-humid, cool, dry conditions for *A. nitida* matched to the drier condition of Trans-Himalayan region. Their occurrence in these habitats indicates that the scanty rainfall, warmest month of the year might be sufficient for *A. nitida* species to colonize in new area. The fragmented climatic conditions of Nepal also favour the patchy and fragmented habitat of *A. nitida*.

The moist region along the river valley reaching the upland overlaps the niche of both species below the Dhaulagiri and Annapurna range in Western hilly region. This suitable region is projected to be 764.07 km² of total land mass.

More abundantly, LULC predicts the *A. nepalensis* in tree cover forested and urban area. The increase in urbanization though decreases the forest area in Hilly region, there is increase in plantation system for *Alnus*-Cardamom agroforestry system. The tree cover forest type also characterizes *A. nitida*. The N₂-fixing bacteria in such forested land favour the habitat of Alder forest. Topographically the North-West Aspect is another niche region for both *Alnus* species. The moistness along the river valley is provided by the shadow of the Mountains and Hills of those regions. Beside this, the rugged terrain of the arid environment provide suitable habitat for *A. nitida*.

3.2.7.2 Future potential suitability of *Alnus* species (IPCC SRES-A1B 2050)

MaxEnt model through IPCC SRES-A1B scenario for future climate (2050) in Nepal predicts significant changes by 2050 in the distribution of both *Alnus* species examined. The geographic origin of genus *Alnus* is uncertain. Suitability range of focal species decreases by

2.31% for *A. nitida* and 11.36% for *A. nepalensis*. Beside climate, high mountains in the Northern aspect and increasing altitude prevent *A. nepalensis* to disperse its seeds and colonize whereas elevational shift of *A. nitida* are affected by summit trap phenomena. The cold adapted *A. nitida* are stressed by climate warming and compete with the range shift species as they migrate upwards until they reach the highest elevations (Salick *et al.*, 2009). The summit inhibits the species to migrate upwards resulting in the extinction. The increasing frostiness in the high altitude are intolerant to *A. nepalensis* but *A. nitida* can easily resist the frostiness. The young seedling are defoliated by frost and very often killed. The published papers also focused on decreased forested area in Siwalik range mainly due to urbanization, deforestation. The migrated species *A. nitida* despite of having slow gain rate, it decreases its ranges. The result suggests that the overlapped region basically gain their niche where the N₂-fixer *Alnus* trees are climatically favourable.

Projecting niche model into future is not only impossible to evaluate (Araujo and Guisan, 2006) but also uncertain due to the use of different climatic Global Climate Models (GCMs) (Buisson *et al.*, 2009). Our MaxEnt model for IPCC SRES-A1B scenario 2050 predicted reduction in suitable habitat area more than gained area. Contrary to these, the stable area is more. Thus the gained and stable area for both species in 2050 will be key areas for conservation of the species as well as for agroforestry system. *A. nepalensis* is wide ranging species and is expected to expand its range under climate change. This stood out quite clearly under SRES-A1B scenario of future change in climate and habitat. Unlike, *A. nitida* being more specific in their habitat preference tend to contract under the assumption of future change. The results also suggest the altitudinal movement of species under climate change for *A. nepalensis*.

MaxEnt also produces clamping and extrapolated maps indicating areas of predictive uncertainty. These uncertainty occurs when future scenario environmental variables contains values which are not within the training range (Rodder *et al.*, 2013). In term of climate, minimum temperature of coldest month for future SRES-A1B scenario in the South of Siwalik were higher than those found in training data. The environmental variables outside these training ranges extrapolate most creating uncertainty in prediction. The western region and central Himalaya will be the climatically suitable niche for *A. nepalensis* and *A. nitida* respectively.

CHAPTER 4

CONCLUSION AND RECOMMENDATION

4.1 Conclusion

Ecological niche modelling (ENM) is an effective tool for assessing environmental similarity between regions where Nitrogen fixing *Alnus* species widely distribute. The distribution and concentration of the plant species in particular region are an index of overall Biogeography of an area. As discussed by Peterson *et al.* (2003), we must also possess an understanding of other factors including colonization opportunity, details of demographics and dispersal ability of focal species.

Climate is the main predictor for the identification of region which is potential for the Alder. The uniqueness of this study is forecasted range shift of *Alnus* species in Nepal due to climate change combined with other variables such as LULC and land facets.

Our Ecological Niche Model by MaxEnt was successful in delineating the niche of focal species. The suitable regions were associated with precipitation and temperature. The driest quarter in the western Himalaya for *A. nitida* and warmest quarter throughout Nepal except in Terai and High Mountain for *A. nepalensis* limits the distribution. The wide variation in the species is due to precipitation where *A. nitida* receives very less rainfall throughout the year.

It was observed that North-West shift of *A. nepalensis* will lose its range in 2050. This lose in range are mostly in lower belt of hilly region in Central and Eastern region. Similarly, only *A. nitida* which is geographically localized in western region will lose its area in 2050. But, the region with combine forest species of *Alnus* will gain its area. The stable or gained area represent potential region for social forestry and agroforestry system. The model mostly extrapolates in the Terai region and high mountainous region. The Terai regions are mostly influenced by bio_6 and High Mountains mostly in the Northern region. The increase in Northness decreases the Suitability region.

Agroforestry systems help farmers adapt to climate change mitigating through carbon sequestration (Luedeling *et al.*, 2014). This system is more complex than monoculture situations. They consists of annual and perennial plants, which are often integrated with

livestocks (Luedeling *et al.*, 2014). In context to Nepal, these multipurpose agroforestry tree species are beneficial for large cardamom which is the important perennial cash crop. The intercropping of alder and cardamom is highly successful agroforestry system. This system was introduced from Sikkim to Ilam (Eastern Nepal) about 40-60 years ago. Mostly Cardamom requires shade, so it is normally intercropped under various types of trees. The chief shade providing tree is *A. nepalensis* which is used in large cardamom based traditional agroforestry system in the region (Sharma *et al.*, 1998). But the shifting trend of *A. nepalensis* might cause depletion in the current agroforestry system in Nepal. Though it has high germination rate, the frost intolerant might reduce their population. Most of the seedlings are defoliated by insects *Anomala spp.* and *Oreina spp.* or stem borers pests *Batocera spp.* and possibly *Zeuzera spp.* (Neil, 1990; Orwa *et al.*, 2009). So it should be highly focused on the management strategy for the conservation of *A. nepalensis* in the stable region. Beside this, *A. nitida* can be regarded as suitable if climate favour for intercropping for Alder-Cardamom, Alder-Tea. These trees are more used as fodder, furniture and other multipurpose use as well as in Alder mixed agroforestry. It is the most suitable farm forestry tree in the high valley and mountains because of its frost hardiness, fast growth and nitrogen fixing properties (Sheikh, 1993). *A. nitida* can be easily reproduced from seed and by vegetative means. It has no known insects or pest problems.

The maps generated from the model should be considered as a base line data for focal species. Because it has presence and pseudo-absence record of the particular species and validated from multi evaluation process. So, all those results can be used as inputs for conservation and prioritization. The most accurate predictive map for each species was used to identify potentially suitable niche as the core area.

4.2 Recommendation

1. Ecological niche is essential for conserving biodiversity as well as the sustainable livelihoods in the developing countries. Likewise, a potential niche within and around degraded ecosystem provides a powerful tool for maintaining or increasing resilience in natural environments, thereby reducing the vulnerability of these ecosystems in the projected climate change scenario.
2. Beside climatic variable, soil units having their different physical and chemical condition can influence the alder distribution (Wu *et al.*, 2011). So it is highly recommended to use soil unit as the projection layer for the further work.
3. The single predictive model for *Alnus* species creates variability in the forecast of the species under climate change. So it is further suggested to utilize several models as 'Ensemble' forecast improving the robustness of the forecast under climate change (Araujo and New, 2007).
4. The projections onto future climate model did not take into consideration dispersal ability of species. Therefore future research may include a layer that describes dispersal and colonization ability of the species.
5. Due to time constraints the future projection is based only on one scenario. This might cause uncertainty in the projection in future (Beaumont *et al.*, 2008). So projection under different scenarios will help to compare and quantify uncertainties.
6. Impacts on climate change are likely to be particularly severe. It is essential to conserve through communities, governments, NGOs in order to safeguard biodiversity against the uncertainties of climate change. The loss of niche and biodiversity at the local level is due to ecosystem degradation as such it needs global society's response to the ecological management and economic activities.
7. As far as practicable *A. nitida* can also be equally important shade tree which fixes atmospheric nitrogen. So it can also be practiced for intercropping in the suitable geographic region.

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APPENDICES

Appendix 1 Global Land Cover (GLC), 2000 Classification types of Nepal.

GLC 2000 LULC CLASSIFICATION OF NEPAL			
S.N.	GLC 2000 code	LULC type	Description
1	1	Tree cover, broadleaved evergreen, closed to open (>15%)	The main layer consists of broadleaved evergreen closed to open trees. The crown cover is between 100 and 15%. The height is in the range of >30 - 3m but may be further defined into smaller range.
2	2	Tree Cover, broadleaved deciduous, closed (>40%)	The main layer consists of broadleaved deciduous closed to open trees. The crown cover is between 100 and 15%. The height is in the range of >30 - 3m but may be further defined into smaller range.
3	4	Tree cover, needleleaved evergreen, closed to open (>15%)	The main layer consists of needleleaved evergreen closed to open trees. The crown cover is between 100 and 15%. The height is in the range of >30 - 3m but may be further defined into smaller range.
4	11	Shrubcover, closed to open (>15%) , evergreen(broadleaved or needle-leaved)	The main layer consists of broadleaved/needleleaved evergreen closed to open thicket. The crown cover is between 100 and 15%. The height is in the range of 5 - 0.3m but may be further defined into smaller range.
5	12	Shrubcover, closed to open (>15%), deciduous (broadleaved)	The main layer consists of broadleaved deciduous closed to open thicket. The crown cover is between 100 and 15%. The height is in the range of 5 - 0.3m but may be further defined into smaller range.
6	13	Herbaceous cover, closed to open (>15%)	The main layer consists of closed to open herbaceous vegetation. The crown cover is between 100 and 15%. The height is in the range of 3 - 0.03m but may be further defined into smaller range.
7	14	Sparse Herbaceous or sparse Shrub cover	The main layer consists of sparse herbaceous vegetation. The crown cover is between (20 - 10) and 1%. The sparseness of the vegetation may be further specified. The main layer consists of sparse shrubs.
8	16	Cropland (upland crops or inundated/ flooded crops as e.g. rice)	Primarily vegetated areas containing more than four percent vegetation during at least two months a year. The environment is influenced by the edaphic substratum. The vegetative cover is characterized by the removal of the (semi) natural vegetation and replacement with a vegetative cover resulting from human activities. This cover is artificial and requires maintenance. It is grown with the intention to be managed and/or (partly) harvested at the end of the growing season. Before or after harvest

there may be a period without vegetative cover. The environment is significantly influenced by the presence of water over extensive period of time, i.e. water is present for more than three months a year and when water is present less than three months a year, it is present 75 percent of the flooding time.

9	19	Bare Areas	Primarily non-vegetated areas containing less than four percent vegetation during at least 10 months a year. The environment is influenced by the edaphic substratum. The cover is natural. Included are areas like bare rock and sands.
10	20	Water Bodies (natural or artificial)	The land cover consists of artificial water bodies. A further specification can be made in flowing or standing water. The land cover consists of natural waterbodies.
11	21	Snow or Ice (natural or artificial)	The land cover consists of artificial snow. The land cover consists of artificial ice. A further specification can be made in moving or stationary ice. The landcover consists of snow and ice.
12	22	Urban Areas	The land cover consists of built up area(s).

Appendix 2 Description of all environmental variables used for the study.

Category	Variables name	Abb	Attribute	Format	Resolution	Source
Climate	Annual Mean Temperature	bio_1	continuous	ASC	30 arc ~ sec	worldclim data
	Mean Diurnal Range (Mean of monthly (max temp - min temp))	bio_2	continuous	ASC	30 arc ~ sec	worldclim data
	Isothermality (Bio_2/Bio_7) (* 100)	bio_3	continuous	ASC	30 arc ~ sec	worldclim data
	Temperature Seasonality (standard deviation *100)	bio_4	continuous	ASC	30 arc ~ sec	worldclim data
	Max Temperature of Warmest Month	bio_5	continuous	ASC	30 arc ~ sec	worldclim data
	Min Temperature of Coldest Month	bio_6	continuous	ASC	30 arc ~ sec	worldclim data
	Temperature Annual Range (Bio_5 - Bio_6)	bio_7	continuous	ASC	30 arc ~ sec	worldclim data
	Mean Temperature of Wettest Quarter	bio_8	continuous	ASC	30 arc ~ sec	worldclim data
	Mean Temperature of Driest Quarter	bio_9	continuous	ASC	30 arc ~ sec	worldclim data
	Mean Temperature of Warmest Quarter	bio_10	continuous	ASC	30 arc ~ sec	worldclim data
	Mean Temperature of Coldest Quarter	bio_11	continuous	ASC	30 arc ~ sec	worldclim data
	Annual Precipitation	bio_12	continuous	ASC	30 arc ~ sec	worldclim data
	Precipitation of Wettest Month	bio_13	continuous	ASC	30 arc ~ sec	worldclim data
	Precipitation of Driest Month	bio_14	continuous	ASC	30 arc ~ sec	worldclim data
	Precipitation Seasonality (Coefficient of Variation)	bio_15	continuous	ASC	30 arc ~ sec	worldclim data
	Precipitation of Wettest Quarter	bio_16	continuous	ASC	30 arc ~ sec	worldclim data
	Precipitation of Driest Quarter	bio_17	continuous	ASC	30 arc ~ sec	worldclim data
	Precipitation of Warmest Quarter	bio_18	continuous	ASC	30 arc ~ sec	worldclim data
	Precipitation of Coldest Quarter	bio_19	continuous	ASC	30 arc ~ sec	worldclim data
Aridity index (annual)	ai_ann	continuous	ASC	30 arc ~ sec	worldclim data	
Potential Evapo-transpiration (annual)	pet_ann	continuous	ASC	30 arc ~ sec	worldclim data	
Topography	Slope	slope	categorical	ASC	30 arc ~ sec	DEM
	Aspects (Northness)	Northness	continuous	ASC	30 arc ~ sec	DEM
	Aspects (Eastness)	Eastness	continuous	ASC	30 arc ~ sec	DEM
	Terrain roughness	t_rgh	continuous	ASC	30 arc ~ sec	DEM
LULC	Landuse landcover	LULC	categorical	ASC	30 arc ~ sec	GLC2000

Appendix 3 List of Herbarium specimen examined and deposited in different herbaria.

A. *Alnus nepalensis* D.Don

1. Specimens examined

Western Nepal: Ratikhola (Ratanaugla), 2070 m, 13 Dec 1983, T.K. Bhattacharya & P.P. Kurmi 5740 (KATH); *Baitadi*, Satbanj, 1900 m, 21 Sept 1981, I. Sharma, R. Joshi, R. Uprety and I. Pandey 616 (KATH); *Bajhang*, Gandaki near Talkot, 1550 m, 21 July 1976, H. Tabata, K.R. Rajbhandary & K. Tsuchiya 1434 (TUCH); *Bajura*, Bajatoli and Dhamakne, 2030 m, 18 July 1976, H. Tabata, K.R. Rajbhandary & K. Tsuchiya 2584 (TUCH); *Bajura*, Birseni, 1570 m, 19 Aug 1976, H. Tabata, K.R. Rajbhandary & K. Tsuchiya 2663 (KATH); *Dadeldhura*, Dadeldhuralekh, 1580 m, 18 Dec 1986, C.M. Joshi and N. Avasti 40 (KATH); *Dailekh*, Dailekh, 2100 m, 1 Aug 1972, M.S. Bist and D.P. Joshi 131 (TUCH); *Dailekh*, Gairai, 900 m, 25 Feb 1991, N.P. Manandher 349-91 (KATH); *Dailekh*, Khursanibari, 1220 m, 16 Aug 1982, U.R. Poudyal and R.N. Shukla 4101 (KATH); *Dailekh*, Lohari, 790 m, 28 Feb 1991, N.P. Manandher 556-91 (KATH); *Doti*, Jhigadana, 2400 m, 20 Aug 1990, N.K. Bhattarai 90/790 (KATH); *Jajarkot*, Dhunlakot, 2100 m, 13 Aug 1979, K.R. Rajbhandary & B. Roy 4606 (KATH); *Kalikot*, Dillikot, 1850 m, 7 July 1979, K.R. Rajbhandary & B. Roy 3005 (KATH); *Pyuthan*, Khalanga, 1200 m, 10 March 1991, P.P. Kurni, KB 0089 (KATH); *Salyan*, Falabang, 1370 m, 8 May 1984, T.K. Bhattacharya & K.G. Malla 4238 (KATH); *Salyan*, Kapurkot, 1550 m, 20 June 1992, P.P. Kurni KB176 (KATH); *Salyan*, Mokhola, 1220 m, 23 Aug 1983, P.P. Kurmi 5665 (KATH).

Central Nepal: *Baglung*, Jaidi, 1670 m, 29 Oct 2012, S. Sharma 78 (KATH); *Chitwan*, Near Paidi Bas Choki, 390 m, 5 May 1976, R.G. Troth 780 (TUCH); *Dolakha*, Malephu to torikhet, 950 m, 12 July 1977, K.R. Rajbhandary and B. Roy 1237 (KATH); *Dolakha*, Sunkhani, 1520 m, 10 May 2011, B.K. Oliya 89 (KATH); *Gorkha*, Chilaune, 1470 m, 10 May 1987, N.P. Manandhar and C.P. Katel 11570 (KATH); *Gorkha*, Sarjungkhola, 1550 m, 26 July 1994, L. Joshi 9495158 (KATH); *Gorkha*, Sarjungkhola, 1600 m, 26 July 1994, L. Joshi 9495151 (KATH); *Gorkha*, Sarjungkhola, 1650 m, 26 July 1994, L. Joshi 9495168 (KATH); *Kaski*, Dhampus, 1350 m, 21 May 1992, N.P. Manandhar and S.K. Acharya 39-92 (KATH); *Kaski*, Rote pani, 1000 m, 24 June 1986, N.P. Manandhar and C.P. Katel 10900 (KATH); *Kaski*, Tamage-banjan, 1730-2035, 9 Aug 1999, Expedition by the herbal garden Kanazawa university Japan 9961182 (KATH); *Kathmandu*, Dakshinkali, 1530 m, 10 April 1997, S.S. Shrestha 167 (KATH); *Kathmandu*, Gokarna, 1340 m, 2 Nov 1966, P. Pradhan & R. Thapa 6542 (KATH); *Kathmandu*, Kirtipur, 1350 m, 12 May 2003, M.K.D. Shrestha 9 (KATH); *Kathmandu*, Kirtipur, 400 m, 28 Oct 1985, H. Van, I. S. Cotter & J. Metz N184 (KATH); *Kathmandu*, Suryabinayak, 1370 m, 17 April 1991, xx (KATH); *Kavrepalanchowk*, Dapcha, 1740 m, 16 Nov 1988, N.P. Manandhar 12043 (KATH); *Kavrepalanchowk*, Khardarpati, 1550 m, 19 Nov 1988, N.P. Manandher 12139 (KATH); *Lalitpur*, Godawari, 1300 m, 22 June 2001, R.K. Khadka 90 (KATH); *Lalitpur*, Godawari, 1520 m, 13 Sept 2001, N. Joshi 425 (KATH); *Makwanpur*, Old road from Hetauda to Ktm via Bhimpheedi, 800 m, 29 Nov 2004, C.A. Pendry, K.K. Shrestha, S. Dahal, A. Giri, A.G. Miller, N. Pandey, M.R. Pullan, L.R. Shakya, S. Shrestha, M. Siwakoti DNEP2A216 (KATH); *Manang*, Thonche,

1980 m, 12 Aug 1983, N.P. Manandhar 9733 (KATH); *Nuwakot*, Between Grang and Thari east side of Trishuli river, 1900 m, 16 Sept 1966, D.H. Nicolson 2363 (KATH); *Ramechhap*, Kyama-patkare, 2200-2600 m, 4 Aug 1985, H. Ohba, T. Kikuchi, M. Wakabayashi, M. Suzuki, N. Kurosaki, K.R. Rajbhandari and S.K. Wu 8571275 (KATH); *Ramechhap*, Shivalaya-Khasrubus-Deorali, 1000-2700 m, 5 July 1985, H. Ohba, T. Kikuchi, M. Wakabayashi, M. Suzuki, N. Kurosaki, K.R. Rajbhandari and S.K. Wu 8540144 (KATH); *Sindhupalanchowk*, Kakani, 1730 m, 22 May 1993, N.P. Manandher 47-93 (KATH).

Eastern Nepal: Near Nigale, 1600 m, 29 August 1971, P.R.Shakya & M. Ohsawa 1050 (KATH); Phokte-namdo, 1160-1370 m, 1 April 1958, S. G. RaoRolle 13596 (KATH); *Dhankuta*, Hile-pakhribas, 1740 m, 2 July 1988, M.N. Subedi 219 (KATH); *Dhankuta*, Hile-Pakhribas-Golikharka, 1770 m, 2 July 1988, M. Suzuki, N. Naruhashi, S. Kurosaki, Y. Kadota, M.N. Subedi, M. Minaki, S. Noshiro, H. Ikeda 8840007 (KATH); *Dhankuta*, Pakhribas, 1490 m, 15 July 1995, C.M. Joshi 12190 (KATH); *Dhankuta*, Patle, 1670 m, 30 July 1976, N.P.Manandhar 57 (KATH); *Khotang*, Khanidanda-Sherakhola-Diktel-mixakhola-Dorpa Churi Danda, 1050-1670 m, 29 Oct 1995, M. Mikage, T. Kajita, F. Kiuchi, N. Kondo, P. Lacoul, M. Suzuki and K. Yonekura 9555078 (KATH); *Phidim*, Lalikhaira, 2000 m, 18 Nov 1978, P. Pradhan, N.P. Manandhar and N.Acharya 1055 (KATH); *Sankhuwasabha*, Chyangrima-chhokm KHOL-camp site, 2280 m, 21 Aug 1998, S. Noshiro, N. Acharya, K. Kobayashi, Y. Omori, K. Shinozaki and H. Tsukaya 9840114 (KATH); *Taplejung*, Dumhan, 1 Nov 1963, H. Hara, H. Kanai, H. Kurosawa, G. Murata, M. Togashi and T. Tuyama 6303371 (KATH).

2. Specimens deposited at Herbarium, University Museum, University of Tokyo (TI)

Collection date	Locality	District	Altitude(m)	Collection no.	Collector(s)
8/17/1997	Bhotebas - Gogane - Chichila – Kaptane	Sankhuwasawa		9755094	S. Noshiro et al.
2/12/2003	Palung - Daman, Nepal		1056		T. Watanabe et al.
10/29/1995	KhaniDanda - SheraKhalle - Diktel - MiyaKhola – DorpaChuriDanda	Khotang	1450	9555078	M. Mikage et al.
9/21/1996	RituKharka - Lulang - Lumsung - below Lumsung	Myagdi	2180	9686196	M. Mikage et al.
9/1/1996	Ratnechour – Beni	Baglung	830	9686008	M. Mikage et al.
1/19/1996	Sauraha - Padampur - Bhawanipur – HardaKhola	Chitawan		9611796	M. Mikage et al.
9/2/1995	Junbesi - Tagtor - a pass - Lanjura Pass - Goyom - Dakchu - Sete – Kensa	Solukhumbu		9596597	F. Miyamoto et al.
8/29/1971	near Nigale		1600	1050	M. Ohsawa & P.R. Shakya

10/23/1971	above Nhorbu Gaon		2100	997	M. Ohsawa & P.R. Shakya
5/5/1976	Royal Chitwan National Park	Chitawan	390		R.G. Troth
9/23/2007	Simigaun(2030m) - Tamakoshi bridge(1430m) - Lamabagar(1970m) - Gungurkhola(1300m)	Dolakha	2110	20740712	S. Noshiro et al.
9/13/2007	Dolakha(1750m) - Nagdaha(890m) - Malephu(940m) - Gumukhola(920m)	Dolakha	925	20740003	S. Noshiro et al.
9/13/2007	Dolakha(1750m) - Nagdaha(890m) - Malephu(940m) - Gumukhola(920m)	Dolakha	980	20740151	S. Noshiro et al.
9/13/2007	Dolakha(1750m) - Nagdaha(890m) - Malephu(940m) - Gumukhola(920m)	Dolakha	980	20740150	S. Noshiro et al.
9/13/2007	Dolakha(1750m) - Nagdaha(890m) - Malephu(940m) - Gumukhola(920m)	Dolakha	995	20740149	S. Noshiro et al.
9/13/2007	Dolakha(1750m) - Nagdaha(890m) - Malephu(940m) - Gumukhola(920m)	Dolakha	960	20740148	S. Noshiro et al.
9/13/2007	Dolakha(1750m) - Nagdaha(890m) - Malephu(940m) - Gumukhola(920m)	Dolakha	960	20740147	S. Noshiro et al.
9/13/2007	Dolakha(1750m) - Nagdaha(890m) - Malephu(940m) - Gumukhola(920m)	Dolakha	925	20740146	S. Noshiro et al.
9/13/2007	Dolakha(1750m) - Nagdaha(890m) - Malephu(940m) - Gumukhola(920m)	Dolakha		20740145	S. Noshiro et al.
9/13/2007	Dolakha(1750m) - Nagdaha(890m) - Malephu(940m) - Gumukhola(920m)	Dolakha	925	20740144	S. Noshiro et al.
9/13/2007	Dolakha(1750m) - Nagdaha(890m) - Malephu(940m) - Gumukhola(920m)	Dolakha	925	20740143	S. Noshiro et al.
9/15/2007	Jagat - Phedi - Buthu – Simigaun	Dolakha	1580	20740163	S. Noshiro et al.
9/15/2007	Jagat - Phedi - Buthu – Simigaun	Dolakha	1580	20740164	S. Noshiro et al.

9/15/2007	Jagat - Phedi - Buthu – Simigaun	Dolakha	1580	20740165	S. Noshiro et al.
9/15/2007	Jagat - Phedi - Buthu – Simigaun	Dolakha	1580	20740166	S. Noshiro et al.
9/15/2007	Jagat - Phedi - Buthu – Simigaun	Dolakha	1670	20740167	S. Noshiro et al.
9/15/2007	Jagat - Phedi - Buthu – Simigaun	Dolakha	1970	20740168	S. Noshiro et al.
9/22/2007	Dongang - Kelche - Suchek – Simigaun	Dolakha	2845	20740698	S. Noshiro et al.
9/16/2007	Simigaun(2030m) - Suchek(kharka)(2490m) - Kelche(2810m) - Dongang(2780m)	Dolakha	2825	20740381	S. Noshiro et al.
9/16/2007	Simigaun(2030m) - Suchek(kharka)(2490m) - Kelche(2810m) - Dongang(2780m)	Dolakha	2810	20740383	S. Noshiro et al.
9/16/2007	Simigaun(2030m) - Suchek(kharka)(2490m) - Kelche(2810m) - Dongang(2780m)	Dolakha	2810	20740384	S. Noshiro et al.
8/9/1999	Tamage-Banjan	Kaski	1950	9961182	M.Mikage et al.
8/1/1977	Shemma - Yakuwa – Lamobagar	Sankhuwasawa		770299	H. Ohashi et al.
8/2/1977	Lamobagar - Gola - above Shinbun	Sankhuwasawa		771940	H. Ohashi et al.
8/3/1977	Above Shinbun – HatiaGola	Sankhuwasawa		771970	H. Ohashi et al.
8/5/1977	HatiaGola - Digatedra - TaramBhanjyang – Honkon	Sankhuwasawa		773483	H. Ohashi et al.
9/3/1977	Sindua - Hile - Dhandkuta – TekuNala	Dhankuta		775560	H. Ohashi et al.
9/20/1963	Sundarijal Waterfall	Kathmandu	1600	6303366	H. Hara et al.
9/22/1963	Gokarna Forest	Kathmandu		6303367	H. Hara et al.
10/18/1963	Dhankuta	Dhankuta	1200	6303368	H. Hara et al.
10/19/1963	Dhankuta	Dhankuta	1200	6303369	H. Hara et al.
10/29/1963	Minchin Dhap – MulPokhari	Sankhuwasawa		6303370	H. Hara et al.
11/1/1963	Dumhan – Taplejung	Taplejung		6303371	H. Kanai et al.
11/10/1963	Helok – BaroyaKhimty	Taplejung		6303372	H. Hara et al.
7/7/1983	Suiket – Pathana	Kaski		8340051	H. Ohba et al.
7/5/1985	Shivalaya - Khasrubus – Deorali	Ramechhap		8540144	H. Ohba et al.
8/4/1985	Kyama – Patkare	Ramechhap		8571275	H. Ohba et al.
7/2/1988	Hile (Hille) - Pakhribas - GholiKharka (Dholikharka)	Dhankuta	1770	8840007	M. Suzuki et al.
7/2/1988	Hile (Hille) - Pakhribas - GholiKharka (Dholikharka)	Dhankuta	1830	8860007	M. Suzuki et al.

8/18/1988	Pokhara - Bagar - Hyangja - Suikhet - Majhbhatti - NaudandaPhedi (NaudharaPhedi)	Kaski	1160	8860430	M. Suzuki et al.
9/13/1988	Forest Office - Chhap - Shiwapuri Summit	Kathmandu	1620	8861045	M. Suzuki et al.
7/23/1990	Hile - Pakhribas – GholiKharka	Dhankuta	1800	9040023	M. Minaki et al.
8/13/1991	Baidep - Arun River – Num	Sankhuwasawa		9153461	H. Ohba et al.
5/11/1992	Mitlung - Thuma – Khokling	Taplejung	790	9261005	M. Suzuki et al.
5/14/1992	Papung - Dongen – Sewaden	Taplejung	2260	9261019	M. Suzuki et al.
5/24/1992	RamsyangPati - Jongim - WolangchungGola	Taplejung	2710	9261067	M. Suzuki et al.
6/5/1992	Amjilasa - bend - YanjolarchaKhola – Gyabla	Taplejung	2370	9261174	M. Suzuki et al.
6/6/1992	Gyabla - Nag PokariKhola - Fale – Ghunsa	Taplejung	2740	9261189	M. Suzuki et al.
6/14/1992	Yamphudin-SigreDanda	Taplejung	1900	9261278	M. Suzuki et al.
8/21/1998	Chyangrima - ChhokamKhola - Camp Site	Sankhuwasawa	2280	9840114	S. Noshiro et al.
9/23/1963	Balaju	Kathmandu			H. Hara et al.
7/26/2003	Godawari	Lalitpur	1570		T. Watanabe & K.J. Malla
11/24/2003	Sagakgaon	Gorkha			T. Watanabe & K.J. Malla

3. E-herbaria at Royal Botanical Garden Edinburgh (RBGE)

Barcode	Collection no.	Collection date	Collector(s)
E00240540	4441	9/16/1954	Stainton, J.D.A., W. Sykes and J. Williams
E00240656	1960	10/30/1954	Zimmermann, A.
E00293603	60/00	4/8/2000	W.R.Sykes
E00248246	A216	11/29/2004	Second Darwin Nepal Fieldwork Training Expedition
E00223626	9686196	9/21/1996	Botanical Expedition to West Nepal 1996
E00240549	1868	10/27/1954	Zimmermann A.
E00074569	9153461	8/13/1991	East Nepal Expedition to Koshi Zone (1991)
E00156584	9611796	1/19/1996	Botanical Expedition to Central Nepal, Chitwan (1996)
E00240539	3760	3/31/1952	Polunin, O., W. Sykes and J. Williams
E00240545	1868	10/27/1954	Zimmermann, A.
E00083102	9686196	9/21/1996	Mikage, M., R. Hirano, A.Takahashi and K. Yonekura
E00649206	280/99	4/27/1999	Sykes, W. R.
E00083140	9040023	7/23/1990	Botanical Expedition to Himalaya (1990)
E00250164	BY11	9/11/2005	Third Darwin Nepal Fieldwork Training Expedition

4. Occurrence points reported through field visits.

Locality	District	Altitude(m)
Aghor, Namtar-3	Makwanpur	1850
Bahundanda	Gorkha	1690
Chandragiri	Thankot	2050
Chitre	Parbat	2020
Dapcha	Kavre	1490
Dubichaur	Gulmi	1470
Godam	Kathmandu	1690
Gurba-3, Hastichaur	Gulmi	980
Harpukot	Gulmi	1120
Kalikot	Kalikot	2970
Lalitpur	Godawari	2230
Mahadevthan	Kathmandu	1580
Maldi-1, Hastichaur	Gulmi	1050
Naubise	Dhading	1270
Nayagaun, Daman-5	Makwanpur	2140
Panchase	Parbat	2830
Phidim	Phidim	1600
Phulchoki	Lalitpur	1760
Satghumti, Thakre-8	Dhading	1090
Thankot	Kathmandu	1950

B. *Alnus nitida* (Spach) Endl.

1. Specimens Examined

Western Nepal: *Bajhang*, Dhuli, 2120 m, 25 July 1976, H. Tabata, K.R. Rajbhandari and K. Tsuchiya 1586 (KATH); *Bajhang*, Gangadi near Talkot, 1550 m, 21 July 1976, H. Tabata, K.R. Rajbhandari and K. Tsuchiya 1434 (KATH); *Darchula*, Makari gad – Khandeswori, 2090 m, P.R. Shakya, H.K. Adhikari and H.N. Subedi 7906 (KATH); *Humla*, Deoli(Darma)-lohachaur, 2400 m, 28 July 1979, P.R. Shakya, M.N. Subedi and R. Uprety 8686 (KATH); *Humla*, Kulli gad, 2400 m, 16 June 2008, K.R. Rajbhandari and B. Roy 4068 (KATH); *Humla*, Rimigaon, 2450 m, 27 July 1979, K.R. Rajbhandari and B. Roy 4014 (KATH); *Humla*, South of Lali, 1980 m, 16 Aug 1985, C.A. Pendry, S. Baral, S. Noshiro, S. Rajbhandari, P.P. Kurmi, B. Dell, B. Adhikari JRS B146 (KATH); *Humla*, Way down from Simikot, 2800 m, 17 July 1968, S.B. Malla 14256 (KATH); *Mugu*, Gamgadhi, 2200 m, 24 July 1979, K. Shinozaki s.n. (KATH); *Mugu*, Gamgadhi-pina, 2100 m, 22 Aug 1985, P.R. Shakya, M.N. Subedi and R. Uprety 8773 (KATH); *Mugu*, Lamagad, 1800 m, 20 July 1979, K.R. Rajbhandari and B. Roy 3814 (KATH); *Mugu*, Pina, 2250 m, 13 Oct 1975, N.P. Manandher and D.P. Joshi 6962 (KATH); *Mugu*, Pinna, 2400 m, 20 July 1979, T.B. Shrestha and N.P. Manandher 214 (KATH); *Mugu*, Thyarigaon, 2350 m, 9 Aug 1981, K.R. Rajbhandari and B. Roy 3646 (KATH); *Mugu*, Thyarigaon, 2400 m, 16 Sept 1995, K.R. Rajbhandari and B. Roy 3645 (KATH).

2. E-herbaria at Royal Botanical Garden Edinburgh (RBGE)

Barcode	Collection no.	Collection date	Collector(s)	cite as:(Stable URL)
E00240657	1960	10/30/1954	Zimmermann, A.	http://data.rbge.org.uk/herb/E00240657
E00240654	5243		Polunin, O., Sykes, W. & Williams, J.	http://data.rbge.org.uk/herb/E00240654
E00397283	B146	6/16/2008	Flora of Nepal Collecting Trip (2008)	http://data.rbge.org.uk/herb/E00397283

Appendix 4 Results of jackknife evaluations of relative importance of predictor bioclimatic variables for (a) *A. nepalensis*, (b) *A. nitida* MaxEnt model and Table c for Variable contribution (%) of all Bioclimatic variables for *Alnus nepalensis* and *Alnus nitida* MaxEnt model.

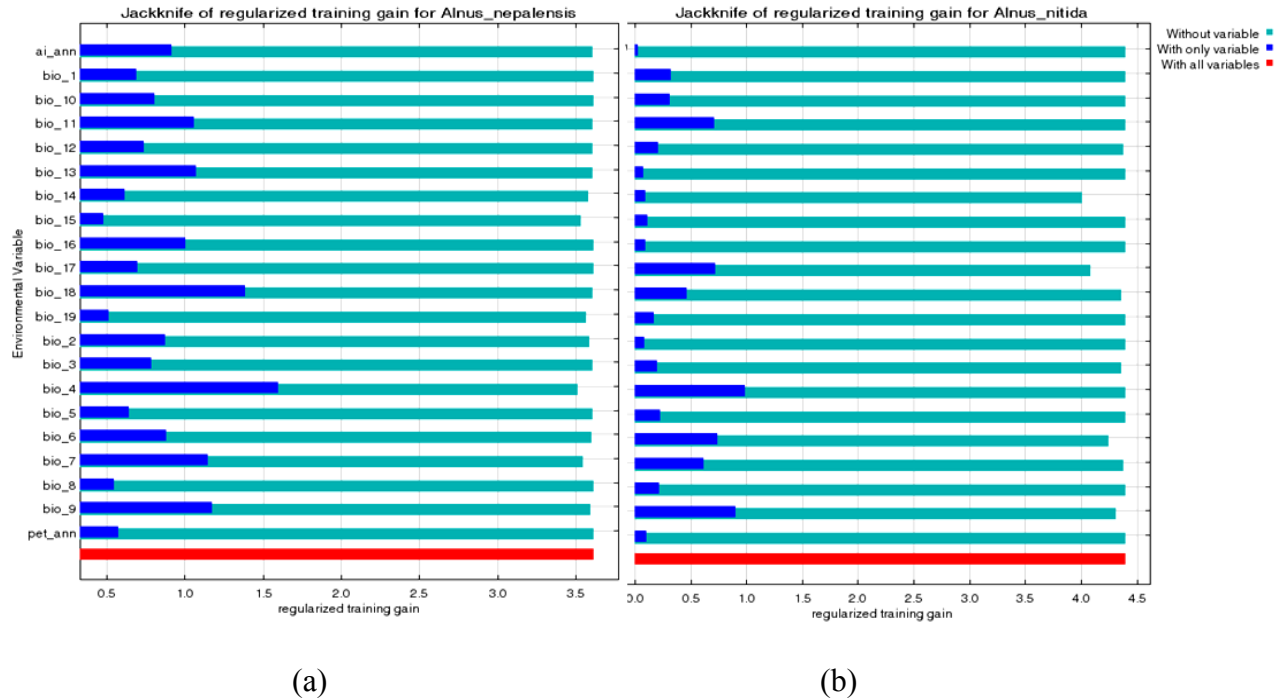


Table c Variable contribution (%) of all Bioclimatic variables for *Alnus nepalensis* and *Alnus nitida* MaxEnt model.

Variables	bio-18	bio-11	bio_3	bio_13	bio_15	bio_1	bio_4	bio-19	bio_6	bio_7	bio-14
<i>Alnus nepalensis</i>	28	18	15	13	5.9	4.7	3.5	3.42	2.69	2.18	1.2
	bio_2	bio_5	bio_9	ai_ann	bio_12	bio_10	bio_16	bio-17	bio_8	pet_ann	
	0.8	0.6	1	0.3	0	0	0	0	0	0	
<i>Alnus nitida</i>	bio_18	bio_11	bio_3	bio_13	bio_15	bio_1	bio_4	bio-19	bio_6	bio_7	bio-14
	7.2	25	1	0	0	0.3	27	1.17	4.53	3.7	15
	bio_2	bio_5	bio_9	ai_ann	bio_12	bio_10	bio_16	bio_17	bio_8	pet_ann	
	0	0	1	0	2.9	0	0	10.7	0	0	

Appendix 5 Percent contribution of variables for *A. nepalensis* and *A. nitida* (model 4).
 (* and ** are 1st and 2nd important probable suitable variables for both species respectively)

Variables	Percent contribution	
	<i>A. nepalensis</i>	<i>A. nitida</i>
bio_18*	25.5	17.8
Slope**	16.6	32.9
LULC	12.3	25.2
Northness	9.6	0.5
bio_6	8.2	3.2
Eastness	5.2	1.6
bio_3	5.1	0.1
bio_9	4.6	0.2
bio_17	4.3	7.6
bio_4	4.1	0.8
t_rgh	2.5	0.4
bio_15	2	9.8