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Gokarna Jung Thapa

I do hereby attest that I am the first Author of this Paper and Dr. Eric Wikramanayake and Jessica Forrest are the Main Contributor to this Dissertation and that it contents are only the result of research and Climate Change Modelling using the GIS and Remote Sensing Application.

Signature: 

This Dissertation is dedicated to my Parents (late father) Kailash Thapa, Mother Parvati Devi Thapa, My Wife Champa Kumari Khadka, Daughter Abantika Thapa and Son Adhish Jung Thapa.

ABBREVIATIONS AND ACRONYMS

ACA	Annapurna Conservation Area
BCN	Bird Conservation Nepal
CHAL	Chitwan-Annapurna Landscape
CR	Critically Endangered
DEM	Digital Elevation Model
DNPWC	Department of National Parks and Wildlife Conservation
DoF	Department of Forests
GCMs	General Circulation Models
GHG	Green House Gas
GLOF	Glacial Lake Outburst Flood
HadCM3	Hadley Centre Coupled Model version 3
ICIMOD	International Centre for Integrated Mountain Development
IPCC	Intergovernmental Panel on Climate Change
MoE	Ministry of Environment
NAPA	National Adaptation Programme of Action
NCVST	Nepal Climate Vulnerability Study Team
OECD	Organization for Economic Cooperation and Development
RCMs	Regional Circulation Models
SRES	Special Report on Emissions Scenarios
TAL	Terai Arc Landscape
TISC	Tree Improvement and Silviculture Component
USAID	United States Agency for International Development
WWF	World Wildlife Fund

EXECUTIVE SUMMARY

The Eastern Himalayas are considered to be a region of global importance for biodiversity, and the upper montane and alpine ecosystems are included in the portfolio of Global 200 ecoregions identified by World Wildlife Fund (WWF). Nested within these regional-scale ecoregions are specific vegetation types and distinctive floral assemblages that also support habitat specialist wildlife. In Nepal, the forests and grasslands are heavily converted, fragmented, and degraded, and many species and ecological communities are already under severe threat. Larger species such as tiger, Asian elephant, greater one-horned rhinoceros, clouded leopard, snow leopard, and wild dog that require continuous, extensive habitats and the habitat specialists with restricted distributions (e.g., red panda, musk deer) are particularly vulnerable. Forest loss also affects ecosystem function and ecological services that support human communities and national economic investments in agriculture and infrastructure.

In recent years, global climate change been recognized as a significant driver of ecological change. The threats reach into the Himalayas; the Intergovernmental Panel on Climate Change (IPCC) has predicted that the average annual temperature in the Himalayas will increase faster than the global average, along with an increase in precipitation. More recent assessments indicate that temperature and precipitation changes could be greater than the upper bounds predicted by the IPCC. Although the extent and specific nature of impacts on biodiversity are still unclear, shifts in vegetation, species extinctions, and changes to ecosystem service delivery are expected. The cascading, downstream impacts will also affect human livelihoods and lives.

We conducted climate analyses to assess the impacts of global climate change trajectories on the forest vegetation communities in Nepal, with a focus on the Terai Arc Landscape (TAL) and the Chitwan-Annapurna Landscape (CHAL), to help guide landscape scale conservation planning. The analysis and output are meant to be a guiding framework to be used in planning, but with knowledge of natural history, ecology, field data, and other relevant information.

We used the highest (A2A) IPCC Green House Gas (GHG) scenario to project the distribution of eight ecological vegetation zones modified from the vegetation map prepared by the Department of Forests, Nepal, using a global database of climate variables. We also identified climate microrefugia using terrain-based analyses. The results from the former, coarse-scale analysis indicate that most of the lower and mid-hill forests in the subtropical and tropical zones are vulnerable to climate change impacts, whereas the temperate upper montane and subalpine forests will be more resilient to climate change. But the latter analysis shows that forest vegetation in climatically stable microrefugia, sheltered from regional influences of climate change by the highly dissected terrain of the Himalayan Mountains, could remain unaffected.

Thus, the landscape-scale conservation strategies should consider the integration of the larger (>500 ha) patches of contiguous forests with the microrefugia, especially to maintain connectivity along climate corridors. The forest vegetation and habitats in the climate microrefugia will also be important to support smaller, habitat specialist species and other irreplaceable biodiversity of the Eastern Himalayan Global 200 ecoregions. Therefore, some immediate actions will include: a) conservation interventions to prevent further degradation from short-term anthropogenic drivers; b) identify and secure the large patches of climate-resilient forests and the smaller patches in climate refugia in the TAL and CHAL; and, c) strategic restoration and conservation of resilient patches to maintain north-south connectivity for ecosystem functions (e.g., climate corridors for species movements and migrations) and services, and for environmental flows. Climate change-sensitive species should be monitored as indicators of ecological change.

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[1]Note. We use the term climate change ‘resilient’ to include the broader properties of ‘resistance’ to change; i.e., the capacity to remain largely unchanged in the face of climate change.

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1. INTRODUCTION

The Eastern Himalayas are considered to be a region of global importance for biodiversity; the result of the synergistic interactions of the complex mountain terrain, extreme elevation gradients, overlaps of several biogeographic barriers, and regional monsoonal precipitation (Wikramanayake *et al.* 2001a). The distribution of the region's biodiversity has been mapped as ecoregions directed along the horizontal axis of the mountain range (Wikramanayake *et al.* 2001b), and represent the ecological diversity from the Terai-duar grasslands and savannas at the base of the Himalayas to the alpine grasslands at the top, with the range of forest types in-between and along the steep altitudinal cline, from <300 m to > 4000 m. The vegetation that comprises these distinct ecoregions is the consequence of the interactions of elevation, precipitation, temperature, and seasonality (Jobaggy and Jackson 2000, Korner 1998, Ohsawa 1990, 1995).

Nested within these broad, regional-scale ecoregions are specific vegetation types and distinctive floral assemblages; for example, the Eastern Himalayan subalpine conifer forest ecoregion has juniper *(Juniperus)*, fir *(Abies)*, and blue pine *(Pinus wallichiana)* dominated forests; and the Terai Duar Savanna and Grasslands ecoregion has *Saccharum, Imperata,* or *Themeda* dominated grasslands, lowland *sal (Shorea robusta)* dominated woodlands, and *sisoo (Dalbergia sisoo)* dominated riverine forests. Therefore, finer-scale spatial planning for conservation should assess the broad ecoregions for these distinctive floral assemblages and faunal habitat types.

Ecological Costs of Forest and Biodiversity Loss

In Nepal, the forests and grasslands in these ecoregions are heavily converted, fragmented and degraded from anthropogenic activities and land use (Wikramanayake *et al*. 2001b). Consequently, many species and natural ecological communities are under threat of local extinction. Particularly vulnerable are the larger species such as tiger *(Panthera tigris)*, Asian elephant *(Elephas maximus)*, greater one-horned rhinoceros *(Rhinoceros unicornis)*, clouded leopard *(Neofelis nebulosa)*, snow leopard *(Panthera uncia)*, wild dog *(Cuon alpinus)*, and hornbills that require extensive spatial areas to support their ecological and behavioral requirements; species that are persecuted because of their propensity for conflict with people; the habitat specialists species, such as red panda *(Ailurus fulgens)*, musk deer *(Moschus leucogaster)* and several other less charismatic species of flora and fauna; and point endemics[2] with very small range distributions whose habitat can be completely lost from local forest loss and degradation.

Ecosystem degradation also affects the functional integrity of biological communities, compromising ecosystem processes and ecological services that support human communities. The livelihoods, lives, and local and national economic investments in the Himalaya are strongly dependent on these services, especially on sustained and naturally regulated provision of water (Eriksson *et al.* 2009). A clean environment that minimizes diseases, ecosystems that support pollination of crops and provide forest products are some other ecosystem services that are vital for human communities, and loss or degradation of these natural capital-based benefits can have serious repercussions for human well-being and economic and social stability (Ehrlich *et al.* 2012, Foley *et al.* 2009).

[2]Species with extremely restricted, highly localized range distributions.

Global Climate Change

In recent years, global climate change been recognized as a significant driver of ecological change (IPCC 2007a, Parmesan 2006). The Himalayas are no exception; assessments show that the Himalayan mountains are highly vulnerable to global climate change (Beaumont *et al.* 2011, Li *et al.* 2013, Shrestha *et al.* 2012). The IPCC projects that the average annual temperature in South Asia will increase by 3-4°C by 2080-2099 under an A1B (medium-high emissions) scenario, and likely higher under an A2A scenario based on comparisons with historical averages from 1980-1999, while annual precipitation is expected to increase throughout this region (Meehl *et al.* 2007a). More recent assessments indicate that temperature and precipitation changes will be greater than the upper bounds predicted by the IPCC (Shrestha *et al.* 2012). Although a good understanding of the extent and specific consequent changes to biodiversity is still unclear, shifts in vegetation, species extinctions, and changes to ecosystem service delivery are expected, with consequential cascading, downstream impacts on human livelihoods and lives (Xu *et al.* 2009).

2. PROJECTED CLIMATE CHANGE TRENDS IN NEPAL

Nepal's National Adaptation Programme of Action (NAPA) (MoE 2010) documents temperature and precipitation trends and provides national-scale climate projections.

Observed climate variability and change

Temperature data collected between 1977 and 1994 indicate an average increase in temperature of 0.06°C per year nationally, and from 1996-2005 an average increase in the maximum temperature of 0.04°C per year. The increasing trends are, however, variable across the country. Precipitation data collected from 166 stations across Nepal from 1976 to 2005 shows an increasing trend in annual precipitation, but with considerable local variation, including in pre- and post-monsoon precipitation and winter precipitation (MoE 2010). Himalayan glacier melt and retreat have also been documented, with 18 glacial lake outburst flood (GLOF) events recorded in Nepal between 1936 and 2000 (Callot *et al.* 2009).

Projected climate change

The NAPA provides climate projections conducted by the Organization for Economic Cooperation and Development (OECD 2003) and the Nepal Climate Vulnerability Study Team (NCVST 2009). The OECD analysis used Global Circulation Models (GCMs) with the Special Report on Emissions Scenarios (SRES) B2 (low emissions) scenario, and projects mean annual temperature increases of 1.2°C by 2030, 1.7°C by 2050, and 3°C by 2100 relative to a pre-2000 baseline. The NCVST study used Global Circulation Models (GCMs) and Regional Circulation Models (RCMs), and projected mean annual temperature increases of 1.4°C by 2030, 2.8°C by 2060 and 4.7°C by 2090. Both predict warmer winter temperatures. Spatially, the NCVST study shows a higher temperature increase in western and central Nepal relative to eastern Nepal for 2030, 2060, and 2090.

The OECD projections indicate a 5-10% increase in winter precipitation in eastern Nepal, but no change in western Nepal. But monsoon (summer) precipitation is projected to increase by about 15-20% across the country. The NCVST projects an increase in monsoon rainfall, especially in eastern and central Nepal.

The overall projections from these analyses are similar to those of the IPCC that predict a warming trend with variable, unpredictable and extreme weather events (leading to floods and droughts) with increase in rain during the wet season.

One-Horned Rhino *(Rhinoceros unicornis)*

3. CLIMATE CHANGE-INTEGRATED CONSERVATION PLANNING

Given these predicted—albeit uncertain—trajectories, it is important to attempt to better understand the consequences of climate change on biodiversity to develop comprehensive, long-term conservation plans and strategies for implementation. By using a combination of ecological and biogeographical information, spatial analyses, and climate models and data, we can, at the very least, get some sense of the expected changes and integrate them into conservation plans for 'no-regrets' strategies (Hannah *et al.* 2002). These climate change-integrated conservation strategies require that we identify and predict, with some degree of reliability, the trajectories of range shifts in natural habitats under climate scenarios. Climate envelopes have been widely used to predict the future distribution of habitats and species, but they have also been criticized because of the uncertainties associated with predicting climate trajectories and the inability to accurately represent the complex interactions and dynamics of real-world ecosystems (Heikkinen *et al.* 2006, Lawler *et al.* 2006). While the criticisms are justified, bioclimatic models can, however, provide much-needed guidelines for climate change-integrated conservation planning if the limitations are recognized, acknowledged, and the outputs are judiciously used in conjunction with knowledge of the ecology and natural history of the species and ecosystems, and with constant monitoring (Hannah *et al.* 2002, Keith *et al.* 2008, Pearson and Dawson 2003).

In this analysis, we conducted species envelope projections to assess the impacts of global climate change trajectories on broad forest vegetation communities in Nepal. The analysis was conducted at the national scale, but the focus was the impacts in two landscapes: the Terai Arc Landscape (TAL) and the Chitwan-Annapurna Landscape (CHAL) that provide east-west and north-south habitat connectivity, respectively, between important protected areas (Figure 1).

But coarse-scale climate envelope analysis using global and regional datasets can disregard the influence of topography in mountainous regions (Luoto and Heikkinen 2008), and creates climatically stable microrefugia that promotes locally favourable climates despite regionally changing climates (Dobrowski 2010) and promotes local-scale persistence of species and ecological habitats (Randin *et al.* 2009). Therefore, we also used variables based on terrain complexity and insolation based on aspect to identify potential climate microrefugia (Ashcroft 2010, Ashcroft *et al.* 2009, Keppel *et al.* 2012, Olson *et al.* 2012). The resultant outputs from both analyses were used to assess the impact on species of conservation concern[3] and other biodiversity.[4]

[3] Threatened and endangered species, endemic species, wide ranging species, umbrella species.

[4] In its broadest sense; i.e., to include species, populations, and ecological processes.

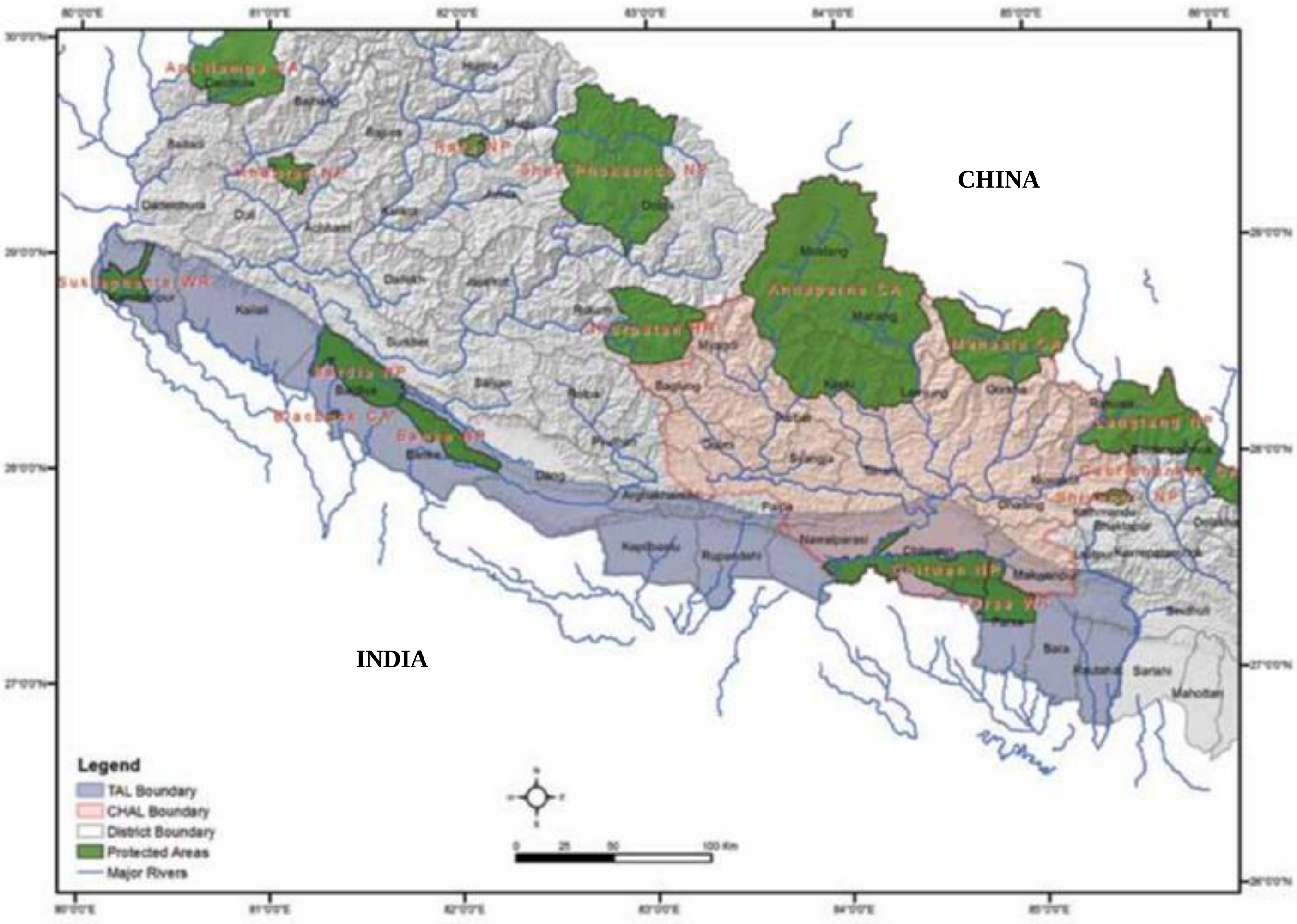

Figure 1. The Terai Arc Landscape (TAL) and the Chitwan Annapurna Landscape (CHAL), with protected areas.

4. USE OF THE OUTPUT FROM THE ANALYSIS AND REPORT

We emphasize that this output report is not meant to be a 'final product', but merely a tool to describe and introduce a framework for the model, database, and analytical process to assess the impact of climate change on habitat and biodiversity and guide landscape-scale conservation planning in Nepal. The database should be regularly updated with new information, and the analysis should be used to monitor, assess, and adapt conservation strategies based on feedback from field conditions.

We also recognize and emphasize the simplicity of the analysis and thus its limitations, and stress that it should not be used as a stand-alone, definitive result, but must be used with knowledge of natural history, ecology, field data, and other relevant information.

We strongly urge that the database be maintained for continued analyses, and that the models should be updated as improved bioclimatic analyses evolve. This will enable the database to be used as a resource for adaptive management; key to climate change adaptation.

5. THE LANDSCAPES

5.1. Terai Arc Landscape (TAL)

The TAL was first designed to protect endangered tiger, rhino, and Asian elephant (Table 1) and the Churia watershed that sustains Nepal's Terai-based agrarian economy (MFSC 2004, Wikramanayake *et al.* 2010). Because of extensive habitat conversion in the Terai, these large species were under threat. All three species have extensive spatial habitat requirements, but were being confined to the protected areas that are considered to be too small as isolated entities to support their ecology, behavior and demographic needs. The goal of the TAL was therefore to conserve—and restore, where necessary—habitat linkages that would allow dispersal between the core populations in protected areas, and thus increase ecological, demographic, and genetic viability. This landscape approach targeted restoration of forested habitat corridors that also helps to conserve and sustain the natural capital of the Churia range. Over the past decade several corridors have been restored and managed through community forestry and community stewardship that provide the local communities with necessary natural forest products. The conservation interventions for these charismatic mega vertebrates also support several endangered but less charismatic species, and critical ecological services that sustain human livelihoods, lives and economic investments.

The TAL primarily represents the habitats of the Terai Duar Savanna and Grasslands and Eastern Himalayan Subtropical Broadleaf Forests ecoregions. The landscape extends along the Churia range and includes the inner *Dun* valleys and the floodplains at the base of the Churia hill range (Figure 1).

Sal (Shorea robusta)
© WWF Nepal, Hariyo Ban Program/ Nabin Baral

The major vegetation types along the riverbanks and floodplains of the TAL are tall grass and *sisoo*-dominated *(Dalbergia sisoo)* forests. The lowlands away from the rivers are *sal (Shorea robusta)* dominated forests, sometimes occurring in mono-stands. The floodplains and lowland areas experience annual monsoon floods that maintain the grass and woodlands by reversing the successional process; in the absence of floods (and to some extent fire) these grasslands would become woodlands and then forests through the natural successional process. Moist mixed riverine forest is common where floods are less severe, but the soil remains waterlogged during the monsoon, whereas the *sal* forests grow on the steeper, dry slopes. During the winter, when river flows are low, the dry beds of braided rivers and adjacent floodplains support near-mono specific stands of *Saccharum spontaneum* grasses that sprout soon after the floods recede. Thus, the Terai grasslands and woodlands are maintained by annual disturbance events (Seidensticker *et al.* 2010).

Table 1. Focal species for conservation landscape planning to maintain habitat connectivity.

Species	TAL/CHAL	Migratory /Dispersal	Climate Sensitive	Large Spatial needs	Habitat Specialist	Umbrella Species
Tiger	**TAL**					
Rhinoceros	**TAL**					
Snow leopard	**CHAL**					
Red panda	**CHAL**					
Musk Deer	**CHAL**					
Altitudinal migrant birds	**CHAL**					
Hornbills, pheasants, tragopans	**CHAL**					
Gharial	**TAL**					
Mahseer	**TAL/CHAL**					

5.2. Chitwan-Annapurna Landscape (CHAL)

The CHAL represents an important north-south corridor that connects the Annapurna Conservation Area (ACA) and other protected areas in the north with Chitwan National Park in the south. Both ACA and Chitwan National Park are iconic protected areas in Nepal that are also globally renowned for their biodiversity. The linkage was first identified during a WWF-supported initiative to develop a conservation vision for the Eastern Himalayan region (Basnet *et al.* 2000). The landscape covers the entire Gandaki river basin in Nepal and includes nine ecoregions (Figure 2), which is an indication of the biodiversity value of this landscape. The deep Gandaki river gorge represents an east-west biogeographic barrier at higher elevations. Because the CHAL straddles this biogeographic barrier, it includes sections of both western and eastern ecoregions and their biodiversity. Thus, the linkage has a diverse biodiversity along both vertical and horizontal axes.

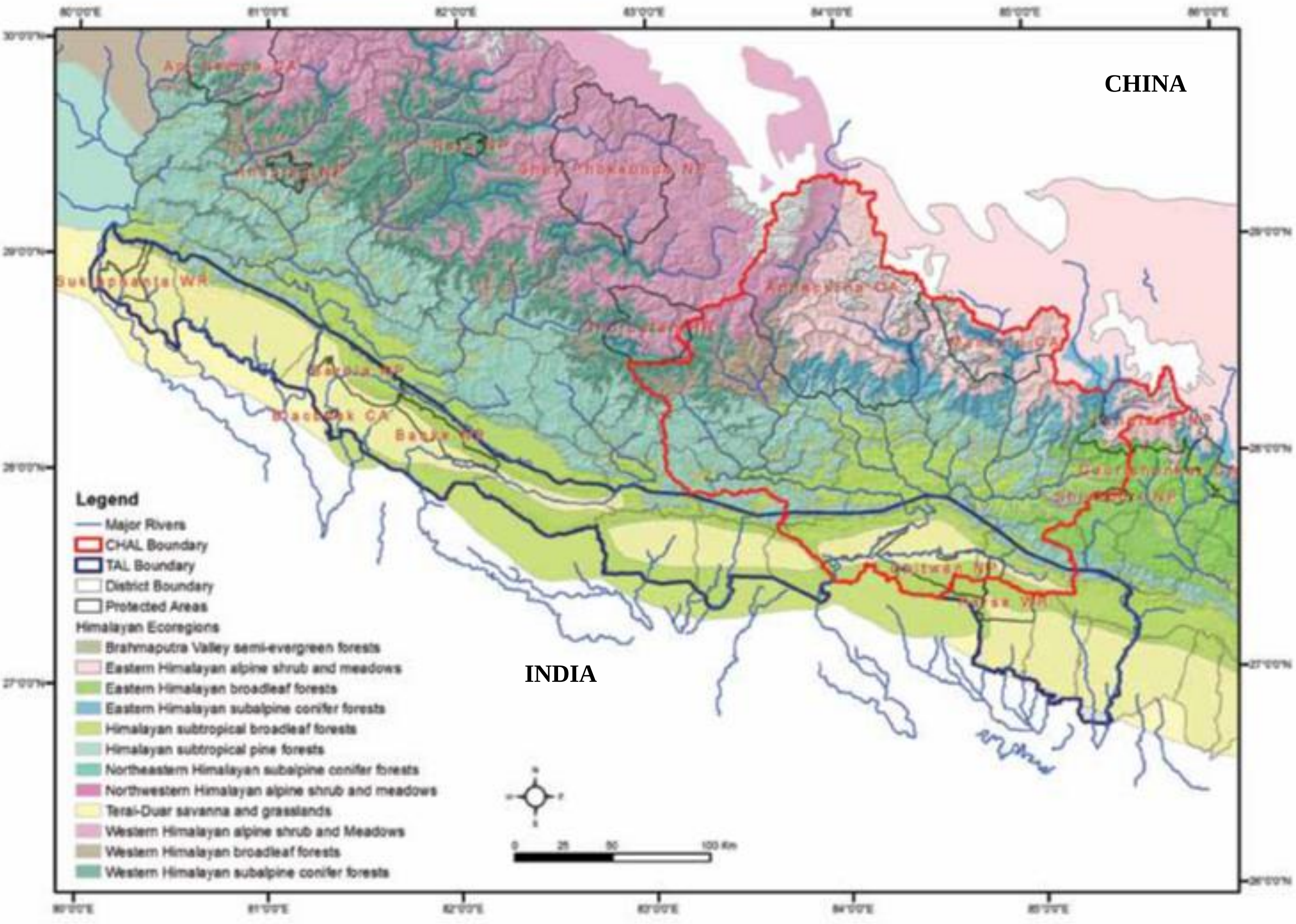

Figure 2. Ecoregions represented in the TAL and CHAL. The Terai Duar savanna and grasslands, and the combined Eastern Himalayan temperate broadleaf forests and Eastern Himalayan subalpine conifer forests represent three Global 200 ecoregions with biodiversity of global importance.

The alpine habitat of the CHAL supports snow leopard and several large, montane ungulate species. The temperate and conifer forests in the upper hill region have habitat specialists, notably the red panda, musk deer, and several species of pheasants, tragopans, and hornbills. The mid-hill subtropical forests represent stepping-stone habitats for a suite of altitudinal migrant bird species that includes several species of cuckoos, flycatchers, sunbirds and pittas. Forest-dependent, wide-ranging species such as clouded leopard, common leopard *(Panthera pardus)*, golden cat *(Pardofelis temminckii)*, wild dog, and Himalayan black bear *(Ursus thibetanus)* also require forest corridors for dispersal and as home ranges or territories. Kingfishers, forktails, mergansers and other waders and waterfowl use the riparian corridors.

Besides supporting species, the forests are also important to sustain vital environmental flows, ecosystem services, and many natural capital benefits. The rivers in the Gandaki basin, notably the Kali Gandaki, Marsyangdi, Seti, Trishuli, and Madi sustain the ecology of downstream natural communities and species, especially in Chitwan National Park with its world-renowned tiger and rhino population. All the rivers have existing and/or planned hydropower investments, and also support the water requirements of the local and downstream communities, and a lucrative water sports industry. Forested watersheds are therefore important to sustain natural ecological communities, human livelihoods and lives, and economic investments by

Red Panda *(Ailurus fulgens)*

sustaining natural river flows, and preventing rapid water runoff and erosion. The rivers also support several fish species, including one of South Asia's largest freshwater species, the Mahseer (*Tor* spp.). The Narayani River also harbours important populations of the Gangetic dolphin *(Platanista gangetica)* and gharial *(Gavialis gangeticus)*. The watershed forests also support bees and other pollinators that contribute to crop pollination.

Although the subtropical and temperate forests of the CHAL have become highly fragmented, conservation of the remaining fragments and strategic restoration to improve connectivity is vital. Continued fragmentation can result in species population declines, further degradation of ecological processes and functions, ecosystem services, and intensification of human-wildlife conflict. Therefore, conservation of the CHAL watersheds is important for biodiversity, people, and national interest.

Both landscapes overlap in the south, in Nawalparasi, Chitwan, Makwanpur and Palpa districts.

6. METHODS

Climate refugia can be assessed along a continuum of scales, from macrorefugia to microrefugia (Ashcroft 2010). Conservation plans should consider the range depending on the conservation targets and objectives. The macrorefugia are important for larger, wide-ranging species, and to include ecological communities and processes, whereas the microrefugia becomes important for smaller-bodied or habitat specialist species with small spatial requirements. Microrefugia are also important for irreplaceable endemic species that become conservation priorities.

Macrorefugia can be identified through coarse-resolution bioclimatic envelope modeling using climate grids interpolated at regional or global scale (e.g., BioClim or WorldClim), but micro-refugia are influenced by local climates created by terrain complexity, temperature sinks, water balance, and insolation, and are usually decoupled from the regional climatic states and changes (Ashcroft *et al.* 2009, Keppel *et al.* 2012). Thus, the microrefugia can be embedded within the larger landscapes, but cannot be identified through coarse-scale models (Ashcroft *et al.* 2009, Dobrowski 2010, Pearson 2006).

6.1. Identifying macrorefugia

We used the IPCC A2A GHG scenario (IPCC 2007b) to project the potential future distributions of eight forest vegetation zones to identify macrorefugia for species habitats and ecological communities. The A2A represents the highest IPCC GHG emission scenario. We chose it as a likely, perhaps even conservative, scenario because recent assessments indicate that GHG emissions during the 2000's exceeded the highest predictions by the IPCC (Hansen *et al.* 2012, Raupach *et al.* 2007, World Bank 2012). Regardless of this fact, we note that conservation planning under climate change should also take into account lower emission scenarios (B1 and A1B), which would presumably result in habitat changes intermediate to present climate and future niches under the A2A emissions scenario. To accommodate uncertainties of climate projections, this model and analytical process should be considered a tool to provide *guidance* in landscape conservation planning, and should be considered and evaluated against other knowledge.

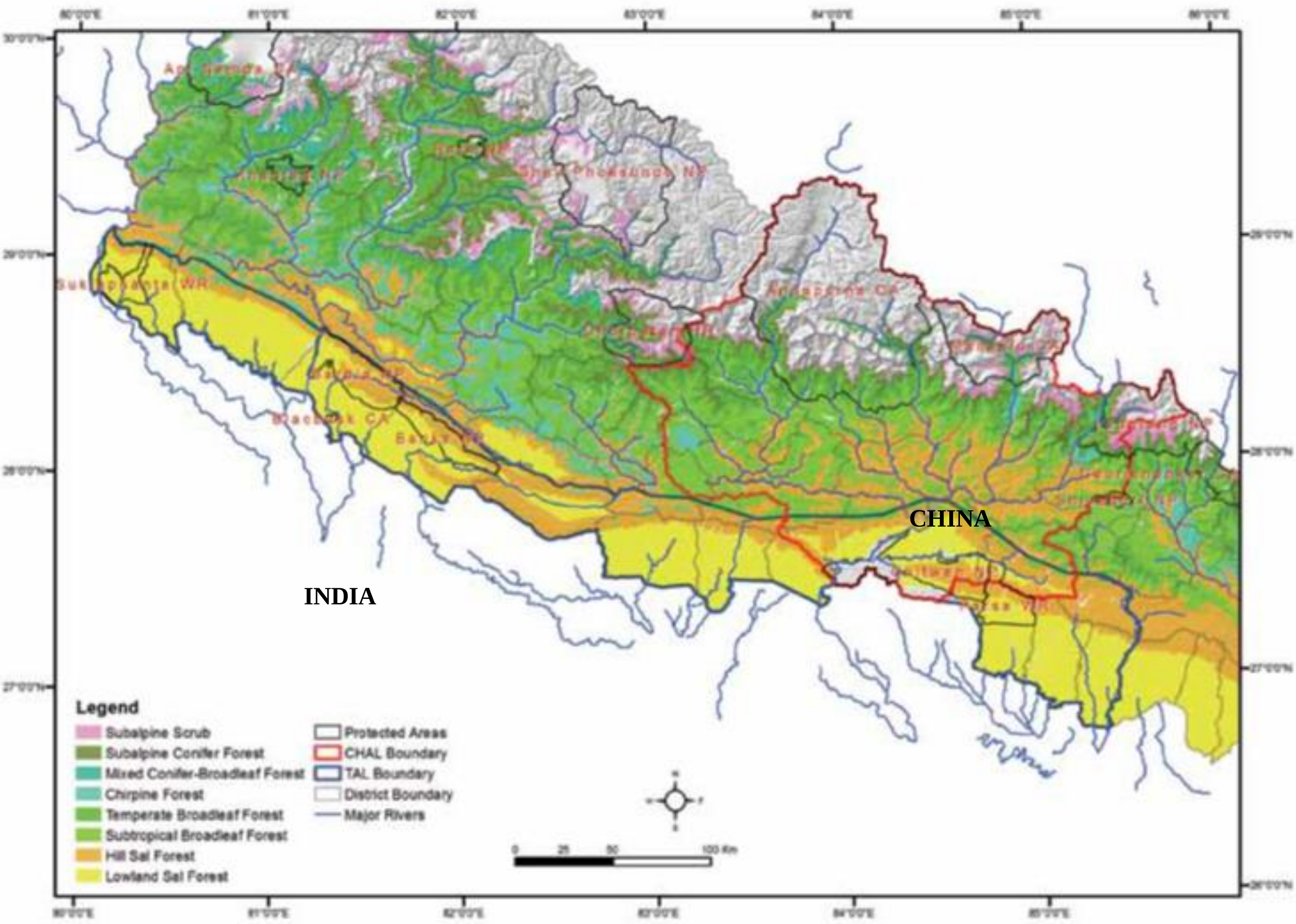

Figure 3. Potential distribution of the eight broad vegetation types. See Appendix 1 for details of the reclassification and relationships of the vegetation types with forest types in the Forest Department map.

Because we aimed to produce maps of the major vegetation types in Nepal under current and future climate conditions, we needed to select occurrence points to train the model that represent the range of climatic and geophysical conditions under which the respective vegetation types may exist. Unfortunately, forests in Nepal are already extensively converted to other land uses. So, producing climate envelope projections from direct observations might not adequately represent all the conditions under which the respective vegetation types may occur. We chose instead to derive occurrence points from the national-scale potential vegetation zone map produced by the Department of Forests (DoF 2002). While this map has its own limitations, we believe it provides our analysis with the most representative sample of occurrence points in current vegetation niches across the different ecological and climatic strata, compared with alternate options based on direct observations or from maps of existing land cover.

We reclassified the vegetation/ forest types from the Department of Forests map into 8 major vegetation types that best represent broadly distributed major wildlife habitat types (see Appendix 1). These vegetation types are 1) Lowland *sal* forest, 2) Hill *sal* forest, 3) Chirpine forest, 4) Subtropical broadleaf forest, 5) Temperate broadleaf forest, 6) Mixed conifer-broadleaf forest, 7) Subalpine conifer forest, and 8) Subalpine scrub (Figure 3). We then generated more than 1,000 random observation points for each vegetation type and entered these into Maxent along with 19 WorldClim bioclimatic variables representing historical climate for the years 1950-2000 (Hijmans *et al.* 2005, Hijmans and Graham 2006, Phillipps *et al.* 2006). WorldClim is a global climate dataset representing historical monthly averages, minima and maxima in temperature, and average monthly precipitation. It was created by interpolating temperature and precipitation values between weather stations, along with elevation data. The bioclimatic variables (Box 1) are biologically meaningful variables derived from the monthly historical temperature and precipitation values.

Box 1. Nineteen Bioclimatic Variables from

WorldClim BIO1 = Annual Mean Temperature

BIO2 = Mean Diurnal Range {Mean of monthly (max temp - min temp)} BIO3 = Isothermality (BIO2/BIO7) (* 100)
BIO4 = Temperature Seasonality (standard deviation *100)
BIO5 = Max Temperature of Warmest Month
BIO6 = Min Temperature of Coldest Month
BIO7 = Temperature Annual Range (BIO5-BIO6) BIO8 = Mean Temperature of Wettest Quarter BIO9 = Mean Temperature of Driest Quarter BIO10 = Mean Temperature of Warmest Quarter BIO11 = Mean Temperature of Coldest Quarter BIO12 = Annual Precipitation
BIO13 = Precipitation of Wettest Month
BIO14 = Precipitation of Driest Month
BIO15 = Precipitation Seasonality (Coefficient of Variation)
BIO16 = Precipitation of Wettest Quarter
BIO17 = Precipitation of Driest Quarter
BIO18 = Precipitation of Warmest Quarter
BIO19 = Precipitation of Coldest Quarter

Available at: http://www.worldclim.org/bioclim

Maxent was used to project the current and future distributions of the 8 vegetation types. The heuristic estimates of relative contributions of the 19 bioclimatic environmental variables to the Maxent model of habitat types under the 2050 and 2080 projections are provided in Appendices 2 and 3.

Future distributions represent equilibrium climate for the years 2050 and 2080 under the A2A GHG emission scenario projected by a downscaled Hadley Centre Coupled Model version 3 (HadCM3) General Circulation Model (GCM) (Ramirez-Villegas and Jarvis 2010). The HadCM3 GCM (Mitchell et al. 2004) was selected because it is a moderate GCM at a global scale and appears to replicate historical climate in Nepal fairly well. The HadCM3 model predicts an approximately 4°C increase in temperature in the study area under the A2 scenario by the year 2100, which is the median GCM prediction for the landscape and just slightly below the average. HadCM3 also predicts an approximately 20-25% increase in annual precipitation, which is slightly higher than the average and median precipitation increases of about 15% across all GCMs (Meehl *et al.* 2007b, Mitchell *et al.* 2004, Zganjar *et al.* 2009). Only 3 GCMs predict that annual precipitation will decrease under future climate change under an A2 scenario.

The vegetation distribution map for the 2050 projection was clipped with the current (as of 2013) forest cover map (DoF 2010) to select the resilient forest patches of each vegetation type (Figure 4). The 'resilient'[5] forest patches represent the areas where the current vegetation composition is not expected to change in the future due to climate-change impacts, and represent climate refugia for climate-sensitive species. The current forest cover overlay masked out the forests that have been already converted through anthropogenic drivers to select only the remaining forest cover. The 2050 resilient vegetation map was then used as a template to clip the 2080 vegetation distribution and select the resilient patches of each vegetation type (Figure 5). The process is outlined in Figure 6.

[5]The term 'resilient' is used in a broad sense to also include climate change resistant forests.

We then overplayed the current protected areas system on the vegetation maps to identify the potentially climate resilient areas that are already protected, and also identified the forest patches that are >300 and >500 ha that represent climate macrorefugia[6] in 2050 (Figure 7).

6.2. Identifying microrefugia

We identified the climate microrefugia (Figure 8) by selecting the major terrain features that can decouple microclimates from the influences of regional climate change. The terrain features used are: 1) cold air drainage areas such as valley bottoms, local depressions and sinks that promote cold-air pooling and maintain temperature inversions; and 2) slope and aspect that have a greater influence on water balance than temperature. In the Himalaya, north and northwest-facing slopes receive less solar radiation and retain more moisture (Panthi *et al.* 2007), representing climate refuge land facets.

We calculated terrain complexity using a ruggedness index applied to the SRTM 90 m Digital Elevation Model (DEM) in ArcGIS 10. The index is an expression of the amount of difference in elevation between adjacent grids of the digital elevation model, based on a calculation of the difference in elevation values from the centroid of a cell and those of the eight cells immediately surrounding it. The squares of the values are then calculated to create positive values and the eight values are averaged. The topographic ruggedness index is then derived by taking the square root of this average value, which corresponds to the average elevation change between any point in a grid and its surrounding area and reflects the combination of steepness, elevation, and rate of change in elevation to identify steep, deep areas that are potential climate microrefugia.

We identified the old growth forests by selecting the forest types classified as closed broadleaf forests, closed needle-leaf forests, and closed mixed forests from the 2010 land use-land cover map of Nepal (DoF 2010). We overlayed the forest map on the microrefugia map to identify the old growth forests that are within these potential terrain-based microrefugia.

We then applied the Solar Radiation extension to the DEM in ArcGIS 10 to identify slopes with north and northwest-facing aspects that receive low levels of insolation and are potential climate-refuge land facets. We clipped the land facets with low solar radiation (which are correlated with north and northwest-facing slopes) with the intact or old-growth forest layer to identify current distribution of intact forest vegetation in aspect-based climate microrefugia. In this calculation we used the SRTM DEM as an input raster with a floating point type for the output raster with watt hours per square meter as units. Default values for the northern hemisphere were used for latitude, sky size, azimuth, and zenith.

We then combined the forests from the aspect and terrain complexity-based analyses to identify intact forest habitats in potential microrefugia. Note that the difference between the two data layers if that the aspect based analysis extracts the forests on north and northwest-facing slopes with less insolation, while the terrain complexity-based analysis selects for land facets that includes other aspects, but in microrefugia with terrain complexity-based stable climatic conditions. Most of the latter are in steep-sloped, shaded gorges, close to rivers and streams and thus kept moist.

[6]Macrorefugia can be identified using climate grids based on elevation-sensitive interpolations (e.g. BioClim and WorldClim), but microrefugia require fine-scale climate surfaces that consider a broader range of factors. See: Ashcroft (2010).

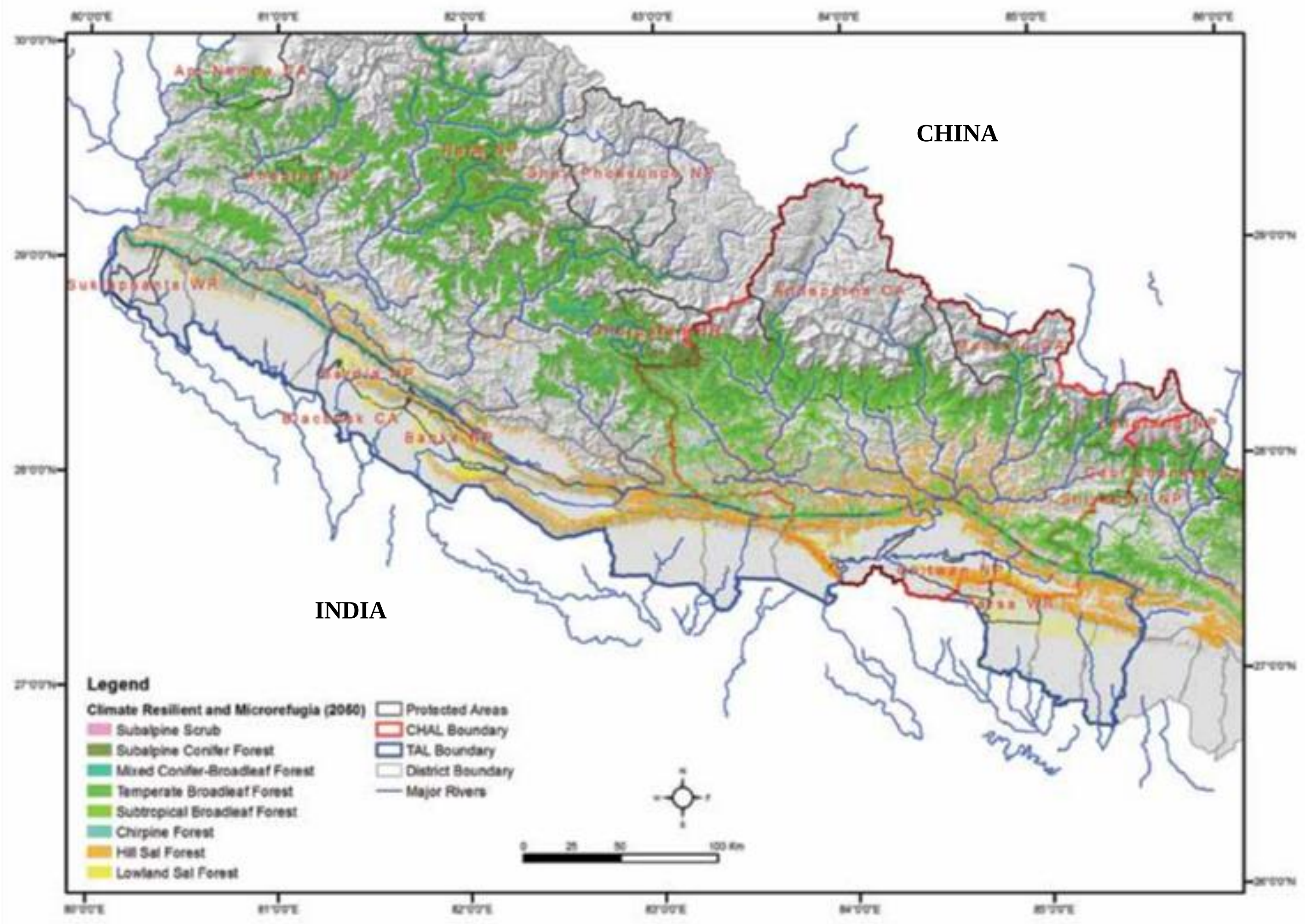

Figure 4. Resilient patches of the vegetation types in 2050 under the A2A climate projection scenario. These patches rep-resent the areas where the vegetation composition is not expected to change under the A2A climate projection, and does not represent forest loss or fragmentation due to non-climate related anthropogenic drivers.

Suklaphanta Wild Life Reserve, Kanchanpur

6.3. Grasslands

The alluvial grasslands and savannas in the Terai were not included as a major vegetation type in this analysis, although the lowland areas identified as lowland *sal* forest generally coincide with the Terai savanna and grasslands ecoregion in Nepal. Unlike forests, the lowland alluvial grasslands are maintained by annual floods and fires, which have a greater influence on grassland ecology than the longer term climate change related drivers. However, changes in annual flow and flood regimes and the frequency and intensity of fires because of climatic change could potentially impact the distribution and species composition of grasslands.

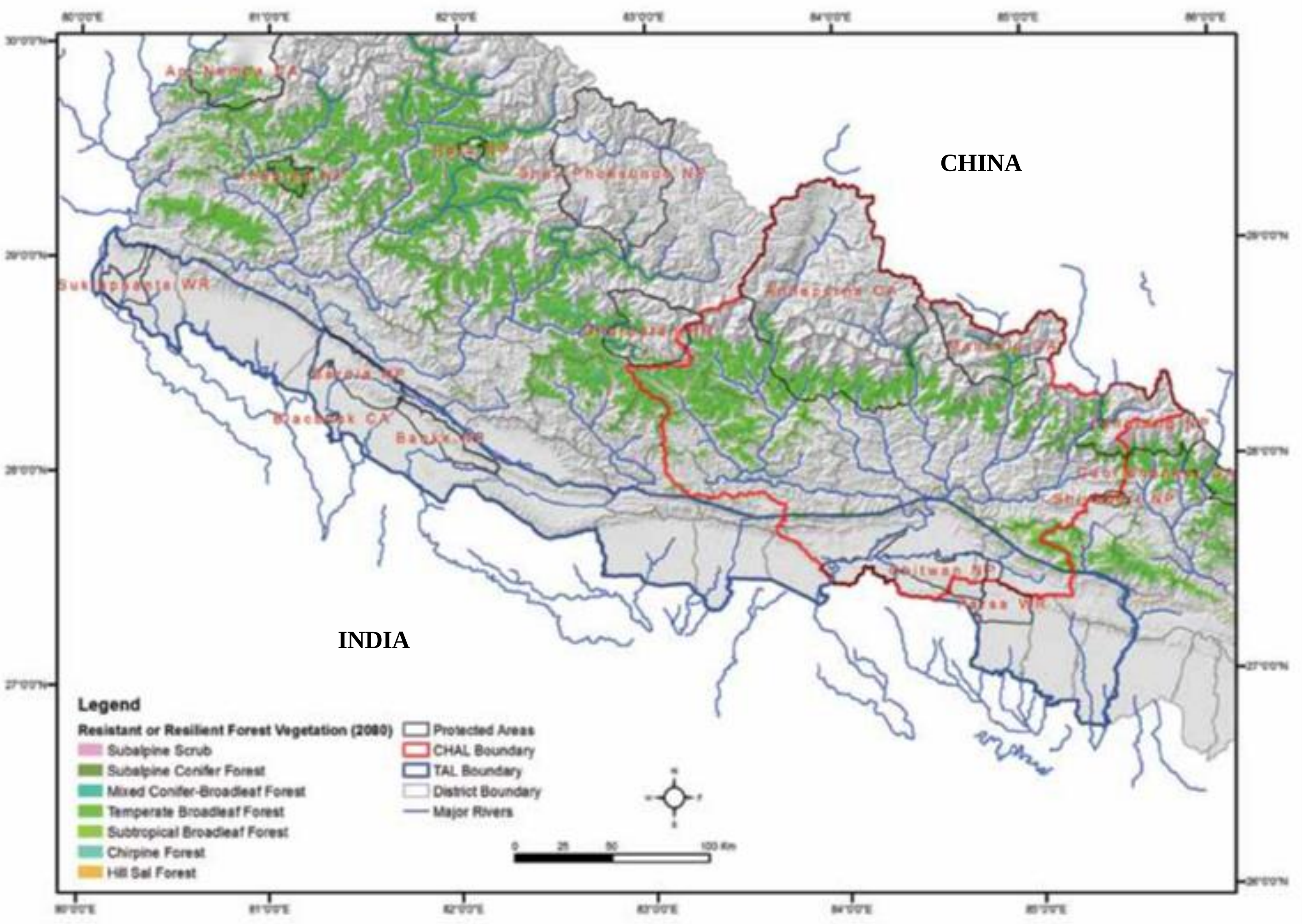

Figure 5. Resilient patches of the vegetation types in 2080 under the A2A climate projection scenario. These patches rep-resent the areas where the vegetation composition is not expected to change under the A2A climate projection, and does not represent forest loss or fragmentation due to non-climate related anthropogenic drivers.

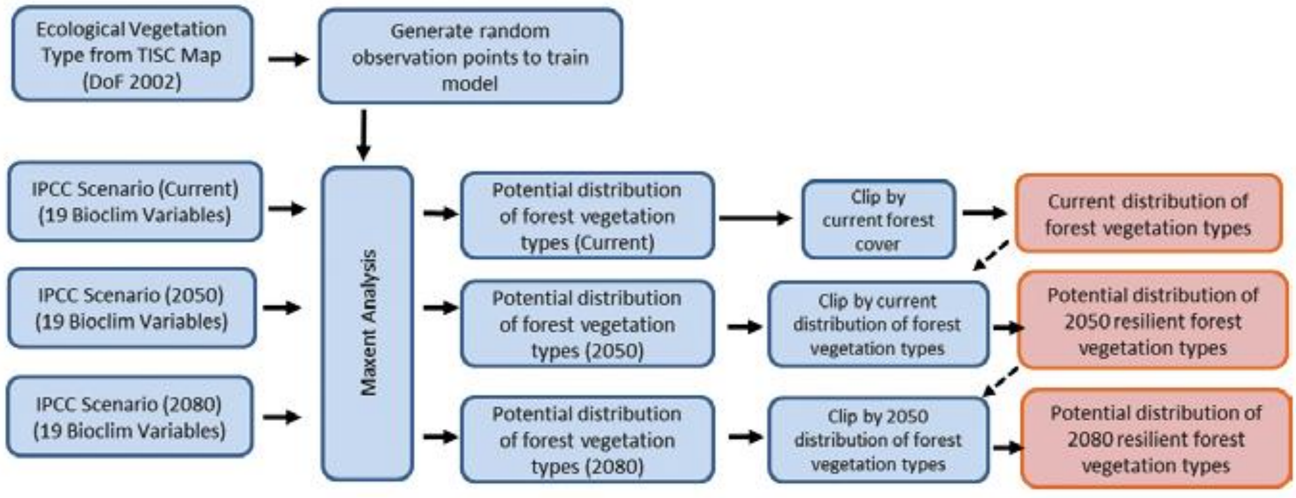

Figure 6. Flow chart indicating steps in climate projection analysis.

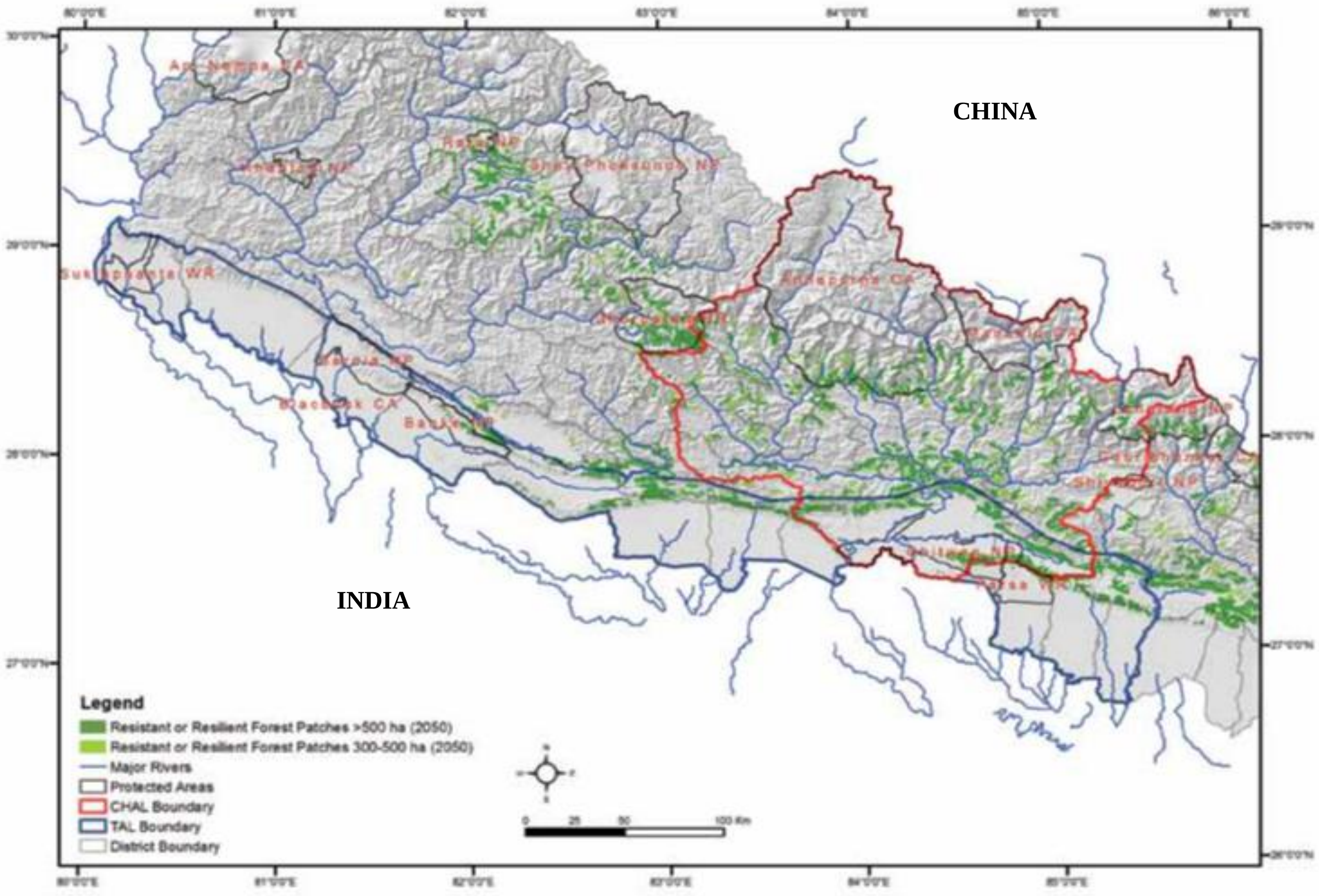

Figure 7. Distribution of larger patches of resilient forests in 2050. These represent potential climate 'macro-refugia' (sensu Ashcroft 2010).

6.4. Range shifts in forest vegetation

In this analysis we do not present changes to the distribution in vegetation types (i.e., range expansions), because different species that comprise the vegetation community could respond differently to the climate change parameters. Thus, the forest types that exhibit range shifts may not have the same vegetation composition. In this context, the areas without resilient vegetation in the map outputs do not represent loss of forest cover or habitat, but only areas where the current vegetation community will be unlikely to persist because of climate change, whereas the ‘resilient patches’ will retain the current species composition because their ‘climate envelope’ will remain within the range of tolerance of the community of existing species. However, there is a possibility that the climate envelope in the latter areas could change at a future time or under a different trajectory, which may be followed by community shifts as well.

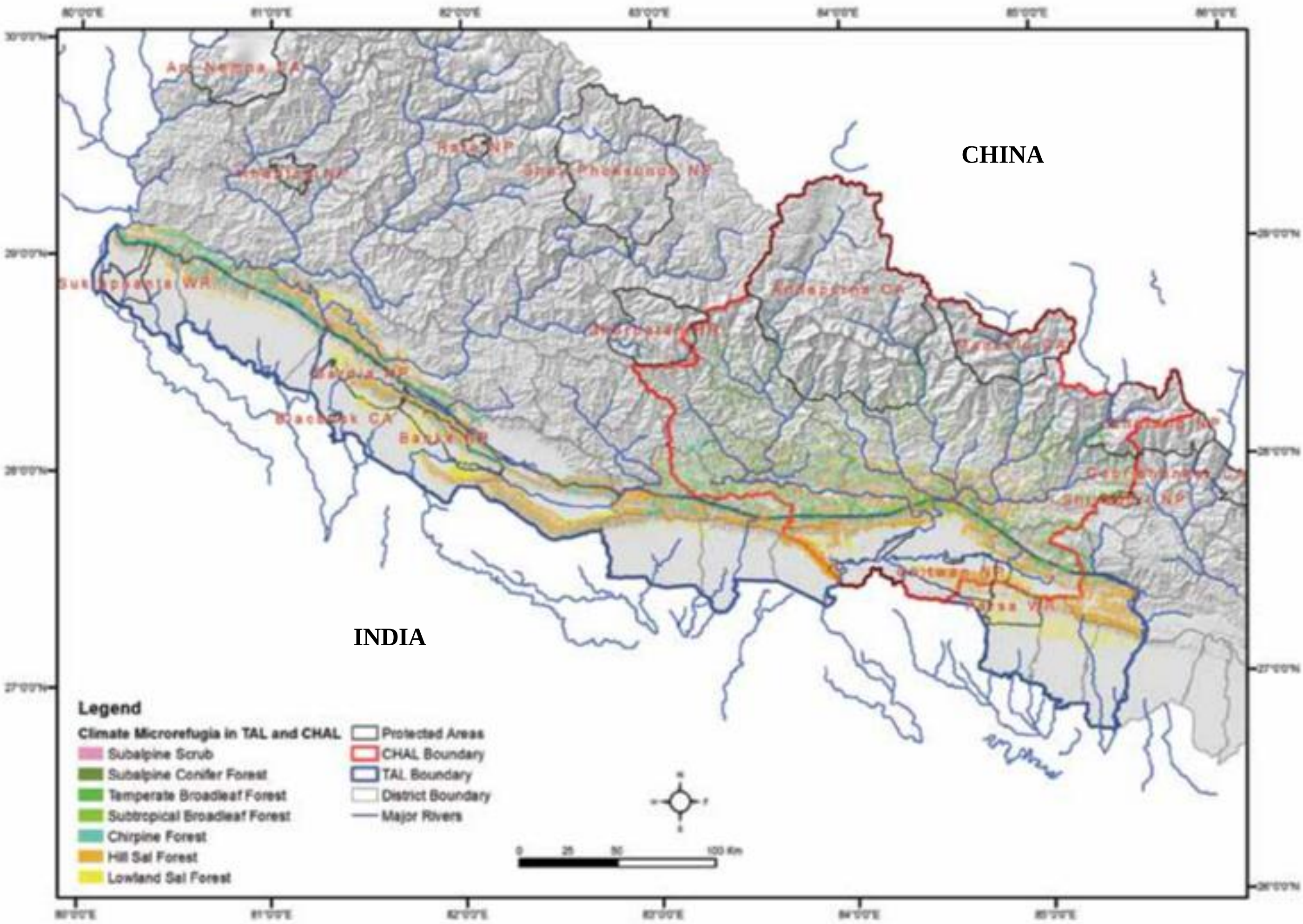

Figure 8. Distribution of climate meso- and micro-refugia (sensu Ashcroft 2010), based on terrain analyses to identify climatically stable meso- and microhabitats.

7. RESULTS

The climate projections based on the global-scale, Worldclim data indicate that most of the lower and mid-hill forests—Lowland sal, Hill sal, subtropical broadleaf, and chirpine forests—are vulnerable to climate change under the A2A GHG scenario. By 2050 the Lowland sal and chirpine forests in both landscapes are projected to become converted to other forest vegetation types (Figure 4).

The hill *sal* forests are now distributed along the Churia range, and northwards into the CHAL. But by 2050, the patches of hill *sal* forests along the Churia are projected to become converted and fragmented (Figure 4), although some larger patches >500 ha will persist along the Churia in Dang, Kapilbastu, Arghakhanchi, and Palpa districts (Figure 7). In the CHAL, small patches will remain scattered in the southern parts of Gorkha, Tanahu, Dhading, and Syanja districts through 2080 (Figure 5).

The subtropical broadleaf forests will become fragmented in both landscapes by 2050, and will become lost from Chitwan, Tanahu, and Nawalparasi districts. The extent of subtropical broadleaf forests in Dhading, Gorkha, Palpa, and Makwanpur will be considerably reduced (Figure 4). By 2080, there will small fragments remaining in Baglung, Kaski, Lamjung, and in northern areas of Makwanpur, Gulmi, and Parbat districts (Figure 5).

The upper montane and subalpine forests will be more resilient to climate change. Larger (>500 ha), resilient patches of temperate broadleaf forests and subalpine conifer forests will remain in Myagdi, Baglung, Kaski, Parbat, Lamjung, Gorkha, Dhading and Rasuwa, with smaller patches extending into the southern areas of Mustang and Manang districts (Figure 7). Some of these forests in Myagdi, Kaski, and Lamjung are within the Annapurna Conservation Area. Most of the subalpine scrub will, however, become converted.

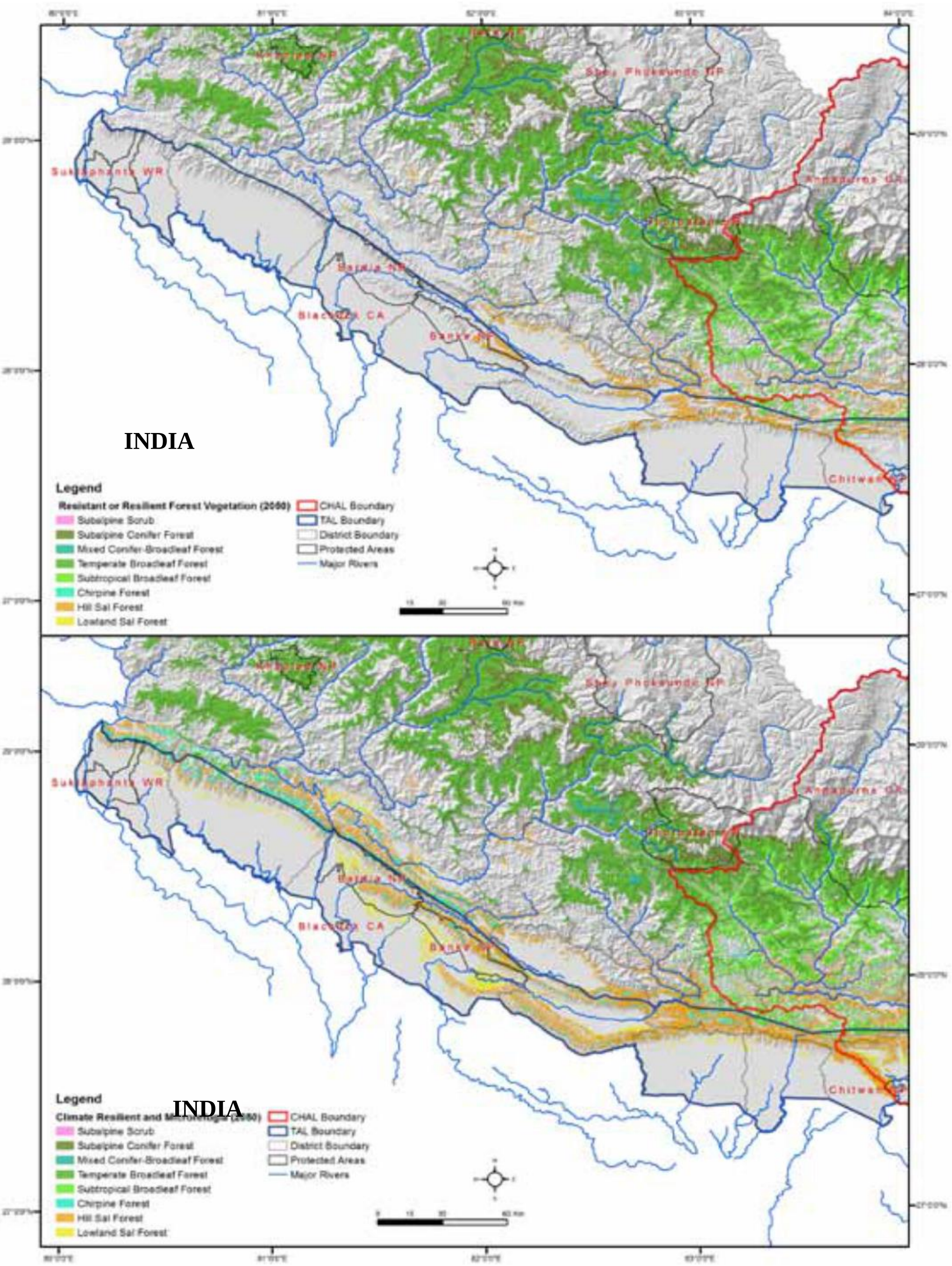

Figure 9. The distribution of forest vegetation types in the TAL, indicating the resilient forests based on the global climate change analysis (top) and the global climate change analysis and terrain-based microclimate refugia (lower).

The analysis of microrefugia using terrain complexity and aspect show that considerable areas of lowland and hill *sal* forests, chirpine forests, and subtropical broadleaf forests are in climatically stable refugia, and will remain decoupled from the regional influences of climate change as projected by global datasets. Thus, most of the Hill Sal forests along the Churia range that were projected to be vulnerable to regional influences of climate change (Figure 4 and 5) will, however, likely remain unchanged because they are in terrain and aspect-based climate microrefugia (Figure 8). In the TAL, many of these forests in climate microrefugia lie along the northern boundary, and also extend to the north-facing slopes of the Churia and into the inner valleys between the Churia and the Mahabarat Hill range further north (Figure 9).

In the CHAL, the hill *sal* forests and the subtropical broadleaf forests in microrefugia help to connect and create larger climate resilient forest patches. The forests also represent climate corridors for climate sensitive species (Figure 8), especially along the steep sided deep gorge of the lower and mid reaches of the Kali Gandaki River as it traverses through Baglung, Syangja, Parbat, and Tanahu districts (Figure 10).

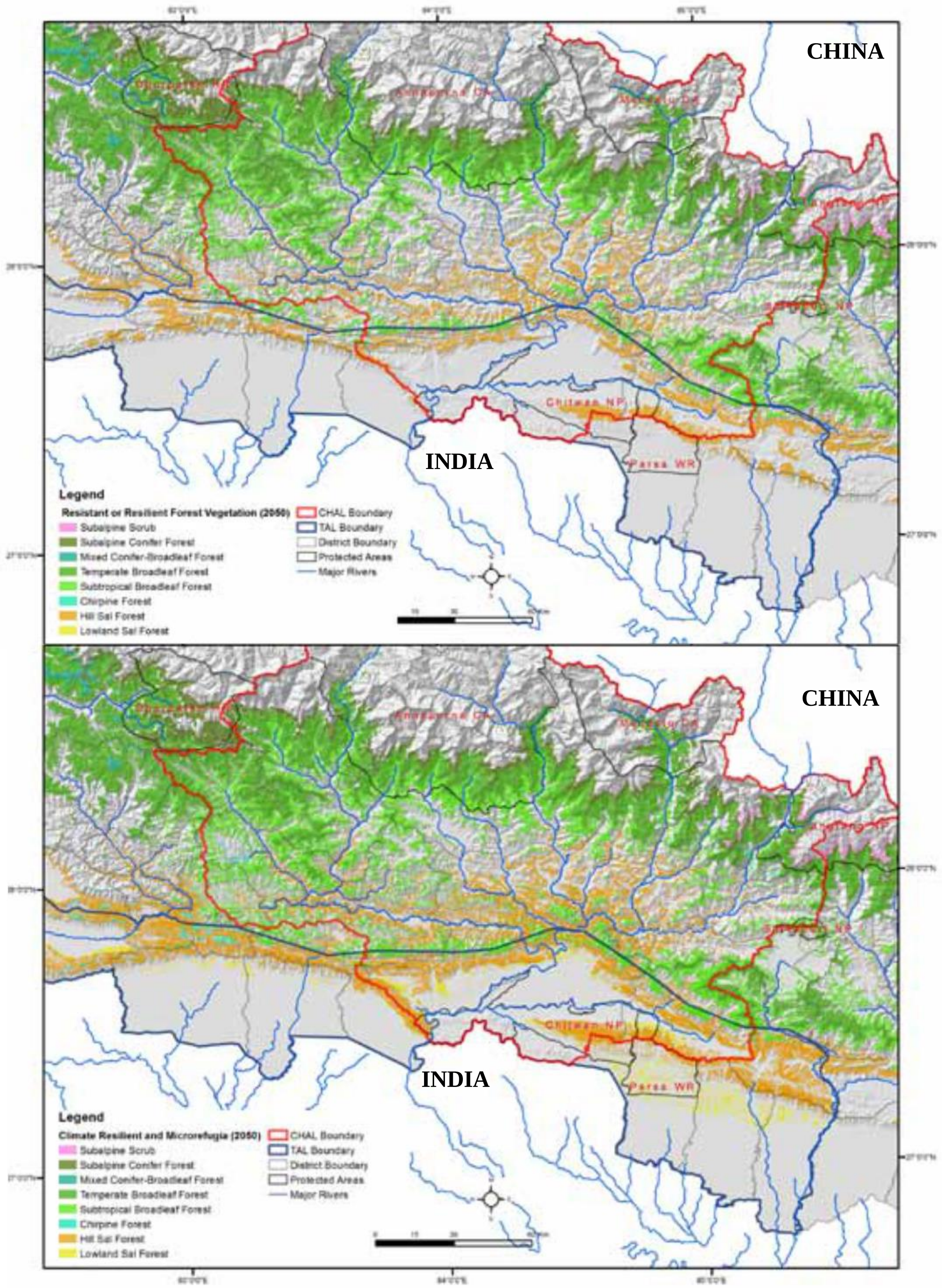

Figure 10. The distribution of forest vegetation types in the CHAL, indicating the resilient forests based on the global climate change analysis (top) and the global climate change analysis and terrain-based microclimate refugia (lower).

Sal Forest, Jumdada Jhapri, Tanahu

8. DISCUSSION

The climate projections indicate that the temperate broadleaf and subalpine conifer forests will be more resilient to climate change impacts even under the highest (A2A) GHG scenarios (Figures 4, 5). Several large patches of these vegetation types will remain (Figure 7), and should be conserved to prevent non-climate related anthropogenic degradation and conversion, and thus loss of important biodiversity. These vegetation types represent the Eastern Himalayan temperate broadleaf and conifer forests and the Eastern Himalayan alpine shrub and meadows ecoregions that are Global 200 ecoregions considered to support biodiversity of global importance (Olson *et al.* 2001). Conservation of these montane ecosystems is also critical to sustain and regulate the hydrological flows in rivers and streams that originate from, and cascade down these watersheds and sub-watersheds providing ecosystem services and environmental flows to human and ecological communities (Eriksson *et al.* 2009).

The mid- and lower-hill forests, however, are more vulnerable to regional climate change. By 2050 the subtropical broadleaf forests will be extensively converted[7] into vegetation types with different species communities, the hill *sal* forests will become highly fragmented within a matrix of different vegetation types, and the lowland *sal* forests will be completely converted in the CHAL (Figures 4, 5). But because of the highly dissected terrain in the mid and lower mountains several forest areas lie within climatically stable microrefugia. Thus, despite the regional influences of climate change, these forests will likely remain largely unchanged (Figures 8, 10).

The TAL has very little subtropical broadleaf and lowland *sal* forests left. Most lowland forests in the TAL have already been converted into settlements, agriculture, and plantations. Some forests are being restored through community forestry, but do not reflect the original vegetation communities, although they do provide habitat for some wildlife species. The remaining hill *sal* forests along the Churia will become fragmented by 2050 due to climate change, but a few larger patches will remain, and these should be conserved, along with the forests in climate microrefugia. The inner valleys to the north of the Churia in particular represent such climate refugia (Figures 8 and 9) for these lowland forests and the biodiversity they harbor. Conservation of these forests along the Churia will also stabilize and protect this fragile mountain range from erosion due to the high rainfall and drought conditions expected from climate change.

8.1. Impacts of Changes to Biodiversity Conservation

The CHAL extends along the Gandaki/Narayani basin and is known to support some of Nepal's most threatened and endangered biodiversity, including habitat specialists and endemic species (Basnet *et al.* 2000). According to Shrestha and Joshi (1996), this area of central Nepal also has some of the highest concentrations of endemic plants, especially in the region between 3000 and 4000 m elevation. The CHAL also supports several species of mammals and birds that are habitat specialists. Notable among these are the snow leopard, red panda, musk deer, several altitudinal migrant birds, and other birds such as hornbills, pheasants and tragopans (Table 1). The snow leopard prefers alpine habitat that is vulnerable to forest encroachment under climate change conditions that could fragment the snow leopard's habitat (Forrest *et al.* 2012). Thus, maintaining horizontal connectivity along the northern alpine zone, as well as maintaining connectivity with the Trans-Himalayan zone through Tibet will become important.

Both red panda and musk deer require old growth temperate broadleaf, mixed conifer-broadleaf, and subalpine conifer forests. The red panda also requires *Arundineria* bamboo in the understory; an even more specialized habitat type than the musk deer. The climate projections indicate that these higher elevation habitats will be relatively more resilient than the lower hill forests, and that several large habitat blocks should remain (Figures 8 and 9). These habitat blocks should be identified through landscape-scale analyses and protected against more proximate drivers of non-climate related anthropogenic habitat conversion and degradation (Yonzon and Hunter 1991).

7Note that 'conversion' in this context does not imply forest loss from non-climate related anthropogenic drivers, but that the current vegetation community will transition into a different vegetation community. Similarly, the reference to 'fragmentation' refers to a process where the climate change drivers break up larger patches within a matrix where the vegetation has transitioned into a different type. It should not be confused with non-climate related anthropogenic forest conversion.

Oriental Pied Hornbill *(Anthracoceros albirostris)*

Conservation of habitats in the climatically stable microrefugia can add to the spatial extent of these habitats, and increase connectivity to sustain the ecological viability of these species.

The greater one-horned rhinoceros has been identified as a habitat specialist that inhabits the Terai grasslands and woodlands in the TAL (Table 1). Because these habitats are maintained by annual floods and fires their distribution cannot be rationally predicted through climate models, which are more long-term projections. Thus, short-term habitat management and monitoring is essential to conserve the habitat for rhinoceros and other grassland species.

Hornbills, tragopans and several pheasants show some habitat specialization (Appendix 4), but may survive in forest types that maintain structural integrity and food plants. For instance, hornbills live in the subtropical and temperate broadleaf forests and require large, old-growth trees for nesting and fruit trees for food. Conservation of the forests in climate microrefugia can ensure that the older canopy trees remain to provide nesting habitats and food trees. Because hornbills also fly long distances between roosting and nesting sites and feeding areas, they can travel to and from forests that have food trees and are not necessarily dependent on continuous forests. However, the tragopans and pheasants require intact undergrowth for feeding and refuge, although they are not specialized to the extent of requiring specific floral assemblages for survival. But forest conversion and fragmentation through non-climate related anthropogenic drivers should be prevented to maintain the structural integrity and ground cover, especially in the larger forest patches.

Other large mammals such as tiger, common leopard, clouded leopard, and wild dog require large spatial areas, but are habitat generalists and are more dependent on prey availability than forest type. Thus, conversion of vegetation from one forest type to another—including grasslands—due to climate change will not have a significant impact on these carnivores as long as adequate undisturbed and connected habitat is conserved. However, survival of large carnivores can become compromised if the prey species populations and access to water are affected (Carbone *et al.* 2011). While the common leopard, clouded leopard, and wild dog are found in the subtropical mid-hill forests of the CHAL, the tiger is now restricted to the TAL. The tiger range extends northwards into the high mountains in Bhutan; therefore it may be possible for tigers in Nepal to shift their range distribution further northwards if the environmental and ecological conditions in the TAL region become unfavourable for survival, and if habitat connectivity and suitable habitat is available in the mountains. Maintaining connectivity in the CHAL through conservation of climate resistant forests and forest in climate refugia could therefore be a viable climate change-integrated conservation strategy for tigers in Nepal.

Most conservation attention in these landscapes have been focused on the charismatic 'megaspecies', but there are several less charismatic species of plants and animals that are habitat specialists with restricted range distributions that could become affected—and even become extinct—because of changes to the vegetation types (see below and in Appendices 5-9). These species should be monitored, and climate resilient habitat should be included in landscape conservation plans. Some of these species are described below.

8.2. Mammals

Of the 180 species of mammals recorded from Nepal, 59 species are listed in the National Red Data Book of Nepal (ICIMOD 2007). The TAL and CHAL support several of these species. The large, wide-ranging species such as the tiger, Asian elephant, snow leopard, common leopard, sloth bear *(Melursus ursinus)* and black bear require large spatial areas to support their ecology and behavior. Several other threatened mid-sized mammals such as wild dog, hyena *(Hyaena hyaena)*, marbled cat *(Pardofelis marmorata)* and golden cat also require habitat connectivity because of their territorial behavior or large home range requirements.

There are also several other large to mid-sized species such as gaur *(Bos gaurus)*, wild water buffalo *(Bubalus arnee)*, red panda, musk deer, clouded leopard, and fishing cats *(Prionailurus viverrinus)* that are habitat specialists. The preferred habitats of these species are already fragmented, with extensive loss from anthropogenic forest clearing, especially in the lowland areas of the TAL. Consequently the lowland species

Bengal Florican *(Houbaropsis bengalensis)*
© WWF Nepal/

are under greater threat; in fact, species such as the pygmy hog *(Porcula salvania)* and hispid hare *(Caprolagus hispidus)* that are highly dependent on early successional dense riverine grasslands are now believed to have been extirpated due to habitat loss.

The climate projections indicate that more habitat conversion and transition will occur in the lowlands and mid-hills, increasing the level of threat. Although the habitat in the higher elevation forest zones—the temperate and conifer forest zones—seem more resilient, it is important to identify climate refugia for species such as red panda and musk deer, which have very specialized habitat requirements.

In addition to the large and mid-sized mammals, there are several smaller species that are restricted to specific forest zones (Abe 1971). The endemic Himalayan field mouse *(Apodemus gurkha)* occurs only in the coniferous and oak forests of central Nepal, between 2,000 and 3,600 m, where it overlaps with the habitat of another habitat specialist, the orange-bellied Himalayan squirrel *(Dremomys lokriah)*. The shrew *(Suncus nigrescens)*, Sikkim vole *(Pitymys sikimmensis)*, smoke-bellied rat *(Rattus eha eha)* and yellow-necked mouse *(Apodemus flavicollis)* occur from the lower temperate forests to the upper coniferous forest zone. The Himalayan water shrew *(Chimarrogale platycephala himalayica)* requires clear streamlets that flow through evergreen forests, and are absent from streams with turbid water. As the temperate and conifer forests are more resilient to climate change, these species will have adequate habitat, unless there is widespread non-climate related anthropogenic forest conversion.

8.3. Birds

Several of Nepal's bird species are migratory. Some are altitudinal migrants that spend summers in the mountains and fly down to the lowlands and foothills for the winter, while others migrate from the Tibetan Plateau and central Asia. The Kali Gandaki valley of the CHAL is an important route for the latter trans-Himalayan migrants that cross the Himalaya along the antecedent river valley, while the altitudinal migrants travel along the river and depend on the forest habitats for food, cover, and resting sites (Inskipp and Inskipp 1991). Thus, conservation of forested habitats in the CHAL is important to maintain the north-south habitat corridors and sustain these bird migrations (Basnet *et al.* 2000).

Nepal lists 149 bird species as threatened, of which 99 species are considered to be Critically Endangered (CR) or Endangered (E) (BCN and DNPWC 2011). Seventy-nine of these are forest-dependent species, 23 are grassland specialists, and 40 require wetlands. Several species within the suite of forest-dependent birds show preferences for particular forest types, such as subtropical or temperate broadleaf forests, different types of conifer forests (e.g., fir or cedar-dominated forests), and broadleaf forests with bamboo (Appendix 4). For instance, threatened species such as Blyth's Kingfisher *(Alcedo hercules)*, Blue-naped Pitta *(Pitta nipalensis)*, Purple Cochoa *(Cochoa purpurea)*, Grey-sided Laughingthrush *(Garrulax caerulatus)*, Blue-winged Laughingthrush *(Garrulax squamatus)*, Black-headed Shrike Babbler *(Pteruthius rufiventer)*, Yellow-vented Warbler *(Phylloscopus cantator)*, Abbott's Babbler *(Malacocincla abbotti)*, White-naped Yuhina *(Yuhina bakeri)*, Broad-billed Warbler *(Tickellia hodgsoni)*, Rufous-throated Wren Babbler *(Spelaeornis caudatus)*, and Himalayan Cutia *(Cutia nipalensis)* show a preference for subtropical broadleaf forests, while Satyr Tragopan *(Tragopan satyra)*, Yellow-rumped Honeyguide *(Indicator xanthonotus)*, Gould's Shortwing *(Brachypteryx stellate)*, Golden-breasted Fulvetta *(Lioparus chrysotis)*, Great Parrotbill *(Conostoma oemodium)*, Brown Parrotbill *(Paradoxornis unicolor)*, and Fulvous Parrotbill *(Paradoxornis fulvifrons)* are usually associated with temperate forests (BCN and DNPWC 2011). Species such as the Satyr Tragopan, Broad-billed Warbler, and White-hooded Babbler *(Gampsorhynchus rufulus)*, require forests with a bamboo understory while the Pale-headed Woodpecker *(Gecinulus grantia)*, Fulvous Parrotbill, and Golden-breasted Fulvetta require pure bamboo stands. Thus, changes to the forest vegetation types or composition due to climate change related drivers can affect these forest-dependent bird species, although more proximate and shorter-term non-climate related anthropogenic drivers are likely to be more severe threats that require urgent and immediate attention.

There are several species of threatened lowland grassland specialist birds, such the Swamp Francolin *(Francolinus gularis)*, Bengal Florican *(Houbaropsis bengalensis)*, Jerdon's Bushchat *(Saxicola jerdoni)*, Greycrowned Prinia *(Prinia cinereocapilla)*, Striated Grassbird *(Megalurus palustris)*, Jerdon's Babbler *(Chrysomma altirostre)*, Slender-billed Babbler *(Turdoides longirostris)*, and Bristled Grassbird *(Chaetornis striata)*, while the alpine grasslands support two globally threatened species, namely the Cheer Pheasant *(Catreus wallichii)* and Wood Snipe *(Gallinago nemoricola)* (BCN and DNPWC 2011). Climate impact projections suggest that the alpine grasslands could become encroached by upslope forest migrations (Forrest *et al.* 2011). However, changes to the lowland grasslands will likely happen more quickly since they are fire and flood-maintained and undergo succession into forests without these natural (or human-induced) processes (Peet *et al.* 1999). Thus, the drivers that maintain grasslands operate at shorter time scales than climate-change related impacts on distribution and migration of vegetation types. However, natural disasters that could increase in severity and frequency due to climate change could have some impact on these birds; for instance, the severe monsoon floods of 2008 destroyed important old growth grassland habitat of the Rufous-vented Prinia *(Prinia burnesii)* (BCN and DNPWC 2011).

Several forest dependent birds are likely to be affected by climate change (Appendix 4). The subtropical broadleaf forests are more vulnerable to climate-related conversion than the temperate broadleaf and conifer forests. Thus, the birds that show a preference for the subtropical zone forests will be especially vulnerable to climate change.

Nepal's mid- and low-hill forests are already severely fragmented, constraining the altitudinal seasonal migrations of several species. Climate change can result in further forest degradation or vegetation changes that can potentially prevent these seasonal movements. Birds that spend winters in the subtropical zones may lose preferred habitats, especially specific food plants or structural habitat features (e.g., nesting or roosting sites or trees) due to changes in forest vegetation or structure. Other migratory birds that spend summers further south, but winter in the mid and low hills of the Himalayas may lose nesting habitats. Thus, conservation of the forests in the microrefugia in the CHAL becomes extremely critical in this context.

Climate change can also affect river flows and riparian vegetation, depending on the severity and frequency of climate change-induced floods and river bank cutting. Several threatened birds are adapted to riverine habitats, and the hydrological and riparian changes can potentially affect these species. For instance, the Ibisbill *(Ibidorhyncha struthersii)* that breeds on the shingle banks along braided channels of high Himalayan rivers could be affected by changing river flows and landslides (Baral 2002, Ghimire and Thakuri 2010). Other insectivorous riverine species such as forktails, dippers, wagtails and river redstarts could face changes in prey abundance if river flows become unsuitable for aquatic invertebrates (Baral 2002).

There are also several wetland birds, such as Sarus Crane *(Grus antigone)*, Cotton Pygmy-goose *(Nettapus coromandelianus)*, Eurasian Curlew *(Numenius arquata)*, Black-bellied Tern *(Sterna acuticauda)*, Indian Skimmer *(Rynchops albicollis)*, Lesser Adjutant *(Leptoptilos javanicus)*, Pheasant-tailed Jacana *(Hydrophasianus chirurgus)* and Baillon's Crake *(Porzana pusilla)* that are highly threatened because of widespread habitat loss. The remaining important wetland areas in Nepal are in Chitwan National Park, Koshi Tappu Wildlife Reserve, Lumbini, Ghodaghodi Lake area, Jagdishpur Reservoir, and the Koshi Barrage. While changes in precipitation and subsequent river flows associated with climate change can affect the wetland habitats in protected areas, the wetlands outside the protected areas face more immediate threats from drainage for conversion to agriculture, extraction of water for irrigation, alteration of stream-flow regimes due to hydropower, pollution, overgrazing of shorelines and marshy edges, and gravel and boulder mining in river beds.

Thus, conservation planning should include the potentially climate resilient forest types in the upper hills and patches of forests in the climate microrefugia as breeding and nesting habitat and to maintain connectivity for altitudinal migrations. However, the more immediate threats to habitat conversion and degradation should also be addressed. Monitoring the bird populations, especially during the migratory season will be an essential requirement.

Himalayan Lizard *(Japalura variegata)*
©Eric Wikramanayake /WWF-US

8.4. Reptiles and Amphibians

Reptiles and amphibians are poorly studied in Nepal. However, the limited information available indicates that there are some species of lizards and frogs that are restricted to specific forest zones. The lizard *Japalura tricarinata* and the frogs *Scutiger sikimmensis* and *Rana sikimensis* are restricted to the oak and rhododendron forests in the temperate broadleaf forest zone (Nanhoe and Ouboter 1987). Three species of amphibians and a skink are restricted to the subtropical broadleaf forest zone, while two reptiles (a lizard and snake) and three species of frogs are restricted to the Subtropical broadleaf and temperate broadleaf forest zones (Appendix 5). Frogs in particular are sensitive to habitat degradation and environmental change, and can be used as indicators of climate change.

8.5. Butterflies

Butterflies can be sensitive to impacts of climate change (Cormont *et al.* 2012, Thomas *et al.* 2006). Some butterfly species require specific host plants for food, either during the adult or caterpillar stage, and changes in vegetation composition of the forest types can affect these species. Surveys in central Nepal (Khanal *et al.* 2012) and in some Terai and Churia districts (Dangdeukhuri, Banke, Bardia, Surkhet) (Khanal 2008) have identified several rare and uncommon butterflies that are restricted to specific forest zones, and to specific forest types within these zones (Appendix 6).

Overall, the Terai zone (<1,000 m) and the broadleaf-conifer zone (3,000-3,500 m) had the highest numbers of rare butterflies (Appendix 6). Khanal *et al.* (2012) have identified several 'forest types' or floral associations defined by dominant tree species within each altitudinally defined vegetation zone (Appendix 6) and assemblages of rare butterflies associated with each. For instance, there are 6 forest types within the mixed broadleaf-conifer forest zone between 3,000 and 3,500 m (Appendix 6). Of these, 23 species of butterfly were recorded from the *Tsuga dumosa, Abies spectabilis, Betula alnoides, Hippohae selecifolia, Rhododendron arboreum* forest type with 11 being rare species. Sixteen butterfly species were recorded from the *Rhus succidenia, Taxus baccata, Leucana leucocephala, Quercus semicarpifolia* forest type, with 8 rare species.

The tropical zone with lowland *sal* forests and Terai grasslands had 30 species of uncommon and rare species (Appendix 6). There is also little or no overlap in the distribution of these species across forest types, possibly reflecting host plant specificity. Because climate projections indicate that the forests in the tropical (Lowland *sal* forests) and subtropical zones (Hill *sal* forests, subtropical broadleaf forests) are vulnerable to change, resilient patches and microrefugia should be conserved for these rare butterfly species, with representation of the different forest associations within each vegetation zone.

Because of their sensitivity to changes in habitat and vegetation composition, short life-spans, and ease of monitoring presence or absence, some of these butterflies can be selected as indicators of climate change.

8.6. Plants

There are several threatened and endemic plant species in CHAL. Several sites along the Marsyangdi, Madi, Seti, and Narayani river valleys have been identified as high species richness areas (Basnet *et al.* 2000). Shrestha and Joshi (1996) have listed 47 species of threatened plant species and 88 species that are endemic to Nepal from the CHAL region (Appendices 7 and 8). The forests in these areas are already fragmented, and the climate projections indicate that the remaining subtropical broadleaf and hill and lowland *sal* forest areas will become extensively converted by 2050, although several patches will remain in climate microrefugia. These climate resilient patches and forests in climate microrefugia should be prioritized for conservation and monitored for change.

9. RECOMMENDATIONS

- The model used the highest (A2A) GHG emission trajectory. Therefore, the resilient forest patches indicated by the outputs are those most likely to persist under conservative projections of climate change. Targeting these patches—especially the larger patches—in a landscape conservation plan will be a 'no regrets' strategy.
- Maintain ecological connectivity through strategic restoration and management of corridors and linkages using climate microrefugia. These will also function as climate corridors to enable species shifts to climate resilient forests. Corridor planning should also maintain connectivity for altitudinal migrations, especially in the CHAL.
- Conserve the microrefugia for the smaller, habitat specialist species that do not require large habitat patches, but require specific habitat types with specific food or nesting plant species.
- Grassland management should also consider the habitat requirements of species other than charismatic mammals, especially the grassland birds.
- Mitigate the more immediate non-climate related threats from habitat conversion and degradation in addition to longer term climate-related threats.
- Monitor for climate-related changes with suitable indicator species, especially amphibians, butterflies, fishes, and sensitive plants.
- Use the climate outputs of this study judiciously, in conjunction with information of the ecology and natural history of species and natural ecological communities. Conduct the analysis using other GHG scenarios and consider those outputs in the planning process as well.

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APPENDICES

Appendix 1. Reclassification of TISC (DoF 2002) vegetation and forest types into the 8 ecological vegetation types for this analysis.

Table also shows the relationships between the TISC (DoF 2002) and Stainton (1972) and LRMP classifications.

LRMP 1986	Stainton 1972	TISC, 2000	This analysis
Sal	*Sal*	Lower tropical *sal* and mixed hardwood forest	Lowland *sal* forest
	Hill *sal*	Hill *sal*	Hill *sal*
Acacia- Dalbergia	*Dalbergia-Acacia*	*Sal* Zone Riverine Habitat	Lowland *sal*
Tropical mixed hardwood	*Terminalia*	Hill *sal*	Hill *sal*
	Tropical deciduous riverine forest	Upper Tropical Riverine Forest	Hill *sal*
	Tropical evergreen forest	Hill *sal*	Hill *sal*
	Subtropical evergreen forest	*Eugenia-Ostodes* forest	Subtropical forest
	Subtropical deciduous hill forest	Hill *sal* forest	Hill *sal*
	Schima-Castanopsis	*Schima-Castanopsis*	Subtropical forest
	Alnus forest	*Schima-Castanopsis*	Subtropical forest
	Subtropical semi-evergreen hill forest	*Schima-Castanopsis*	Subtropical forest
	Castanopsis tribuloides-C. hystrix forest	*Schima-Castanopsis*	Subtropical forest
Quercus spp.	*Q incana-Q.lanuginosa*	Lower temperate oak	Temperate broadleaf forest
Chirpine	*Q dilata*	Lower temperate oak	Temperate broadleaf forest
	Pinus roxburghiii	Chirpine	Chirpine forest
		Chirpine broadleaved	Subtropical Forest
	Upper temperate mixed broadleaved	Deciduous maple-*Magnolia -Sorbus;* mixed Rhododendron-Maple	Temperate broadleaf forest

LRMP 1986	Stainton 1972	TISC, 2000	This analysis
	Lower temperate mixed broadleaved	Mixed oak-Laurel	Temperate broadleaf forest
	Q lamellosa	East Himalayan oak- Laurel	Temperate broadleaf forest
	Lithocarpus pachyphylla	*Lithocarpus* forest	Temperate broadleaf forest
Blue pine	*Pinus excelsa*	Upper temperate blue pine	Subalpine conifer
		Mixed blue pine-oak	Mixed conifer
	Abies pindrow	West Himalayan Fir-Hemlock-oak	Mixed conifer
		Fir-blue upine	
	Picea smithana	Spruce	Subalpine conifer
	Cupressus	Cypress	Subalpine conifer
	Rhododendron forest	Rhododendron forest	Sub alpine shrub forest
	Cedrus	Cedar	Subalpine conifer

Appendix 2. Heuristic estimates of relative contributions of the environmental variables to the Maxent model under the 2050 projection.

To determine the estimate, in each iteration of the training algorithm, the increase in regularized gain is added to the contribution of the corresponding variable, or subtracted from it if the change to the absolute value of lambda is negative.

	Percent Contribution of Bioclimatic Variable							
Bioclim Variable	**Lowland *Sal***	**Hill *Sal***	**Chirpine**	**Subtrop Forest**	**Temp Brdleaf**	**Mixed Conifer**	**Subalp conif**	**Subalp Shrub**
bio1	2.3	57.2	3.3	1	2.7	0.2	2.3	0.3
bio2	0.2	0	3.2	0	23.4	31.7	0.1	2.6
bio3	0.6	0	0.1	0.1	0.2	1.2	1.8	3.9
bio4	0.6	0.3	3.8	1.1	15.3	0.2	22.5	2.6
bio5	14.7	6.3	35.3	29.9	2.9	0.1	0	0.9
bio6	2.2	0.6	9.2	22	12.6	0	7	1.4
bio7	0.1	0.5	3.8	5.8	0	13.3	2.7	0.3
bio8	1.5	7.2	0	6.4	0.1	0.5	17.1	21.3
bio9	1.9	16.7	0.2	4.6	0.7	1.1	0	1.6
bio10	62.7	4.1	0	0	0	0	5.5	8.7
bio11	2.2	3.6	33.6	12.8	39.1	0.2	37.2	33.9
bio12	0.1	0.6	4	6.4	0.2	0.9	0.1	8
bio13	1.3	0.1	0.1	0.4	0	6	0.4	0.1
bio14	0.9	0.2	0.1	1.1	0.2	0.4	0.1	0.1
bio15	5.9	0.3	0.7	1.5	0.3	11.1	0.7	1.6
bio16	0.1	0	0.5	0.2	0.2	4.3	0	6.6
bio17	1.4	0.4	0.7	2.3	0.7	8.3	0.1	0.5
bio18	0.9	0	0.1	0.4	0.1	0.3	1.2	2.6
bio19	0.4	1.6	1.4	3.8	1.4	20.1	1.3	3.2

Appendix 3. Heuristic estimates of relative contributions of the environmental variables to the Maxent model under the 2080 projection.

To determine the estimate, in each iteration of the training algorithm, the increase in regularized gain is added to the contribution of the corresponding variable, or subtracted from it if the change to the absolute value of lambda is negative.

Percent contribution of Bioclimatic Variable

Bioclim Variable	Lowland *Sal*	Hill *Sal*	Chirpine	Subtrop Forest	Temp Brdleaf	Mixed Conifer	Subalp conif	Subalp Shrub
bio1	2.3	57.2	3.3	2	2.6	0.2	2.3	0.8
bio2	0.2	0	3.2	0	11.6	31.7	0.1	2.7
bio3	0.6	0	0.1	0.1	0.2	1.2	1.8	4.6
bio4	0.6	0.3	3.8	0.1	7.9	0.2	22.5	2
bio5	14.7	6.3	35.3	37.5	9.7	0.1	0	0.8
bio6	2.2	0.6	9.2	0.2	5	0	7	4.2
bio7	0.1	0.5	3.8	0.8	9.9	13.3	2.7	0.9
bio8	1.5	7.2	0	0.1	2.8	0.5	17.1	33.4
bio9	1.9	16.7	0.2	15.8	6.3	1.1	0	0.6
bio10	62.7	4.1	0	0.4	0	0	5.5	3.7
bio11	2.2	3.6	33.6	27.6	41	0.2	37.2	21.4
bio12	0.1	0.6	4	6.2	0	0.9	0.1	3.5
bio13	1.3	0.1	0.1	0.2	0.2	6	0.4	4
bio14	0.9	0.2	0.1	0.1	0.3	0.4	0.1	0.9
bio15	5.9	0.3	0.7	1.9	0.2	11.1	0.7	1.8
bio16	0.1	0	0.5	0.1	0.1	4.3	0	9.1
bio17	1.4	0.4	0.7	1.7	0.6	8.3	0.1	0.1
bio18	0.9	0	0.1	2.2	0	0.3	1.2	2.4
bio19	0.4	1.6	1.4	3	1.5	20.1	1.3	3.3

Appendix 4. Some bird species vulnerable to climate change based on potential impacts on habitats.[8]

- Oriental Hobby *(Falco severus)*. Nationally threatened status: CR. Habitat: wooded hills in the tropical and subtropical zone, up to 1525 m. Fragmentation of subtropical and lowland *sal* forests could be potential climate-related threat.
- Jerdon's Baza *(Aviceda jerdoni)*. Nationally threatened status: CR. Very rare and local in distribution. Habitat: broadleaved evergreen forest to 250 m. Fragmentation of subtropical and lowland *sal* forests could be potential climate-related threats.
- Rufous-bellied Eagle *(Lophotriorchis kienerii)*. Nationally threatened status CR. Habitat: evergreen and moist deciduous broadleaved forest from 200-300m. Fragmentation of subtropical and lowland *sal* forests could be potential climate-related threats.
- Mountain Imperial Pigeon *(Ducula badia)*. Nationally threatened status: CR. Habitat: tall, broadleaved evergreen and dense deciduous forests. Forest degradation exacerbated due to climate-related drivers could be threats.
- Vernal Hanging Parrot *(Loriculus vernalis)*. Nationally threatened status: CR. Habitat: broadleaved evergreen and moist deciduous forest up to 300m. Fragmentation of subtropical and lowland *sal* forests could be potential climate-related threats.
- Spot-bellied Eagle Owl *(Bubo nipalensis)*. Nationally threatened status: EN. Rare, local resident. Habitat: dense broadleaved evergreen forests up to 2135 m. Hill *sal* and temperate broadleaf forests could provide climate refugia for this species.
- Dusky Eagle Owl *(Bubo coromandus)*. Nationally threatened status: CR. Very rare and local resident. Habitat: thickly foliaged trees near water up to 250 m. Fragmentation of subtropical and lowland *sal* forests and riparian forests could be potential climate-related threats.
- Tawny Fish Owl *(Ketupa flavipes)*. Nationally threatened status: CR. Very rare. Habitat: heavy broadleaved tropical and subtropical forest in ravines, and banks of streams, rivers and pools from 250-365 m. Fragmentation of subtropical and lowland *sal* forests could be potential climate-related threats.
- Red-headed Trogon *(Harpactes erythrocephalus)*. Nationally threatened status: EN. Very local and uncommon resident. Habitat: dense, broadleaved evergreen tropical and subtropical forests from 250-1000 m. Fragmentation of subtropical and lowland *sal* forests could be potential climate-related threats.
- Ruddy Kingfisher *(Halcyon coromanda)*. Nationally threatened status: CR. Very rare and very local, possibly resident in Churia Hills. Habitat: dense broadleaved subtropical evergreen forest near streams and pools between 200-500 m.
- Blue-eared Kingfisher *(Alcedo meninting)*. Nationally threatened status: EN. Rare and very local. Habitat: streams in dense, shady, broadleaved forest up to 250 m.
- Great Hornbill *(Buceros bicornis)*. Globally threatened status: Near-threatened; Nationally threatened status: EN. Rare and local resident. Habitat: moist broadleaved forest with large fruiting trees up to 250m. Fragmentation of subtropical and lowland *sal* forests could be potential climate-related threats, especially if fruiting trees and nesting trees are lost.
- White-browed Piculet *(Sasia ochracea)*. Nationally threatened status: EN. Rare resident Habitat: broadleaved forest with a preference for bamboo mainly below 915 m.
- Great Slaty Woodpecker *(Mulleripicus pulverulentus)*. Globally threatened status: VU; Nationally threatened status: EN. Rare, local resident. Habitat: mature *sal* forests of the lowlands up to 245 m.

[8]Primarily dependent forest birds, selected on the basis of a) rarity; b) endangered or threatened status, and c) threats to habitat from climate change related impacts. Grassland habitat specialists were not selected because the impacts on grasslands are primarily shorter-term anthropogenic and natural event related.

- Hooded Pitta *(Pitta sordida)*. Nationally threatened status: EN. Very local summer visitor. Habitat: moist subtropical and tropical broadleaved evergreen forest with thick undergrowth up to 305m.
- Sultan Tit *(Melanochlora sultanea)*. Nationally threatened status: EN. Very rare. Habitat: tropical and subtropical evergreen broadleaved forest between 275-1500m.
- Rufous-vented Prinia *(Prinia burnesii)*. Globally threatened status: Near-threatened; Nationally threatened status: CR. Very rare, local. A subspecies is endemic to Nepal. Habitat: undisturbed grasslands. The major monsoon flood of 2008 led to loss and degradation of important grassland habitat; thus climate-change related floods can affect this species.
- White-throated Bulbul *(Alophoixus flaveolus)*. Nationally threatened status: EN. Rare, local resident. Habitat: dense broadleaved evergreen forest up to 455 m, but may show some altitudinal movements.
- Slaty-bellied Tesia *(Tesia olivea)*. Nationally threatened status: EN. Rare, local resident. Habitat: dense undergrowth in dense moist subtropical forest between 1000-1700 m.
- Yellow-vented Warbler *(Phylloscopus cantator)*. Nationally threatened status: EN. Habitat: dense moist subtropical broadleaved evergreen forest from 75-1525 m.
- Broad-billed Warbler *(Tickellia hodgsoni)*. Nationally threatened status: EN. Rare, local resident. Habitat: bamboo undergrowth in dense evergreen broadleaved forest from 2195-2300 m.
- Rufous-faced Warbler *(Abroscopus albogularis)*. Nationally threatened status: CR. Very rare and local. Habitat: bamboo and shrub at edges of moist deciduous and evergreen broadleaved tropical and subtropical forest from 300-1220 m. Some altitudinal movements
- Abbott's Babbler *(Malacocincla abbotti)*. Nationally threatened status: EN. Rare, local resident. Habitat: tangled thickets, especially at tropical forest edges along stream banks up to 275 m
- Coral-billed Scimitar Babbler *(Pomatorhinus ferruginosus)*. Nationally threatened status: CR. Only known in Nepal from a dozen sightings from the Arun valley in E Nepal from 2775 m to 3660m. Habitat: bamboo thickets, dense undergrowth in moist temperate broadleaved forest.
- Spotted Wren Babbler *(Spelaeornis formosus)*. Nationally threatened status: CR. Very rare and local resident. Habitat: understorey of subtropical and lower temperate broadleaved forest with dense undergrowth, ferns and moss-covered rocks from 1200-2300 m.
- Blackish-breasted Babbler *(Sphenocichla humei)*. Globally threatened status: Near-threatened; Nationally threatened status: CR. Very rare and local possible resident. Habitat: broadleaved forest with large trees and bamboo at 500m.
- Rufous-necked Laughingthrush *(Garrulax ruficollis)*. Nationally threatened status: EN. Very local resident. Habitat: thick undergrowth in dense tropical broadleaved forest at 275 m.
- Long-tailed Sibia *(Heterophasia picaoides)*. Nationally threatened status: CR. Very rare and local probable resident. Habitat: broadleaved forest in tropical and subtropical zones from 305-900 m.
- Asian Fairy Bluebird *(Irena puella)*. Nationally threatened status: CR. Very rare. Habitat: subtropical broadleaved and dense moist deciduous forests in central and eastern Nepal, below 365 m.
- Purple Cochoa *(Cochoa purpurea)*. Nationally threatened status: EN. Rare possible resident in central and eastern areas. Habitat: damp, dense broadleaf forests from 915-2255 m.
- Gould's Shortwing *(Brachypteryx stellate)*. Nationally threatened status: EN. Very rare probable resident with altitudinal movements from 600-3500m. Habitat: Breeds in dense rhododendron and bamboo, juniper shrubberies, but winter habitat is poorly known

Appendix 5. Some habitat specialist reptiles and amphibians from the CHAL region.

(From Nanhoe and Ouboter, 1987).

Tropical forest zone <1000 m
Amphibia

- *Rana breviceps* (Ranidae). Restricted to the tropical zone.

Subtropical Forest Zone. 1000-2000 m
Reptilia

- *Sphenomorphus maculatus* (Scincidae). Riverine forests in subtropical zone.
- Amphibia
- *Megophrys parva* (Pelobatidae). Subtropical broadleaf and oak forest. Near streams, 1230-2440 m.
- *Microhyla ornate* (Microhylidae) Subtropical forests.
- *Amolops afghanus* (Ranidae). Small streams in subtropical forest zone.

Temperate Forest Zone. 2000-3500 m
Reptilia

- *Japalura tricarinata* (Agamidae). Habitat: Rhododendron and wet oak forests, 2000-2850 m.
- *Trachischium fuscum* (Colubridae). Wet oak forests.

Amphibia

- *Amolops formosus* (Ranidae). Temperate forests.
- *Scutiger sikimmensis* (Pelobatidae). Streams in dense oak/rhododendron forest.
- *Rana liebigii* (Ranidae). Oak and coniferous forest, from 1500 to 3000 m.

Subalpine conifer forest zone. >3500 m
Reptilia

- *Scincella ladacensis himalayana* (Scincidae). Coniferous forests and alpine meadows >3500 m.
- *Agkistrodon himalayanus* (Crotalidae). Dry coniferous forests *(Picea, Pinus)*. Not recorded from wet oak forests.

Amphibia

- *Rana rostandi* (Ranidae). Limited to coniferous forests between about 2400-3500 m. Recorded only from Kali Gandaki Valley; endemic to the Central Himalayas.

Appendix 6. Rare and Uncommon butterfly species that could be vulnerable to climate change.

Rare butterfly species of forest zones of Central Nepal (from Khanal *et al.* 2012)

Hill *Sal* Forest
Elevation to 1500 m
Forest Type: *Bombax ceiba.*
Total species record: 8 species.
Rare species:

1. *Nacaduba kurava euplea* (Lycaenidae)
2. *Udara albocerulea* (Lycaenidae)
3. *Eurema laeta sikkima* (Pieridae)
4. *Abrota ganga* (Nymphalidae)

Subtropical Forest Zone
Elevation: 1500-2000 m.
Forest Type: *Schima wallichii, Albizzia, Pyrus persica.*
Total species record: 19 species
Rare species:

1. *Achillides arcturus arcturus* (Papilionidae)
2. *Dodona adinora adinora* (Nemeobiidae)
3. *Creon cleobis* (Lycaenidae)
4. *Arophala atrax* (Lycaenidae)
5. *A. singala* (Lycaenidae)
6. *Euthalia aconthea suddodhana* (Nymphalidae)

Forest Type: *Qercus semicarpifolia, Rhus succedenia, Rhamnus nepalensis*
Total species record: 14 species
Rare species:

1. *Cepora nerissa phryne* (Pieridae)
2. *Jamides bochus bochus* (Lycaenidae)
3. *Chliaria kina* (Lycaenidae)
4. *Rapala nissa nissa* (Lycaenidae)
5. *Esakiozephyrus mandara dohertyi* (Lycaenidae)
6. *E. icana* (Lycaenidae)

Forest Type: *Quercus lanuginosa, Alnus nepalensis, Schima wallichii.*
Total species record: 10 species
Only Satyrid species were reported in this forest.
Rare species:

1. *Dallacha hyagriva* (Satyridae)

2. *Lethe rohria rohria* (Satyridae)

3. *L. insane dinarbus* (Satyridae)

Forest Type: *Lyonia ovalifolia, Syzygium cumini, Myrica esculenta, Rhus succedenea*
Total species record: 23 species
Rare species:

1. *Sainia protenor euprotenor* (Papilionidae)

2. *Kaniska canace canace* (Nymphalidae)

3. *Eurema brigitta rubella* (Pieridae)

4. *Mycalesis mineus mineus* (Satyridae)

5. *Jamides celeno aelianus* (Lycaenidae)

6. *Everes lacturnus assamica* (Lycaenidae)

7. *Prosotas nora airdates* (Lycaenidae)

8. *Celastrina marginata marginata* (Lycaenidae)

9. *Heliophoros ila pseudonexus* (Lycaenidae)

Temperate Broadleaf Forest Zone
Elevation: 2000 – 3000 m.
Forest Type: *Alnus nepalensis, Pinus wallichiana, Ribes acuminatum*
Total species record: 11 species
Rare species:

1. *Heliophorus brahma brahma* (Lycaenidae)

2. *Freyeria putli* (Lycaenidae)

3. *Spindasis lohita himalayanus* (Lycaenidae)

4. *Athyma selenophora selenophora* (Nymphalidae)

5. *Telicota bambusae bambusae* (Hesperiidae)

6. *Ochus subvittatus subradiatus* (Hesperiidae)

Forest Type: *Alnus nepalensis, Rhododendron arboretum, Acer campbelli*
Total species record: 16 species
Rare species:

1. *Dodona egeon egeon* (Nemeobiidae)

2. *Borbo cinnara cinnara* (Hesperiidae)

Forest Type: *Alnus nepalensis, Acer campbelli, Myrica esculenta*
Total species record: 23 species
Rare species:

1. *Ancema ctesia ctesia* (Lycaenidae)

2. *Udara dilecta* (Lycaenidae)

3. *Neptis soma butleri* (Nymphalidae)

4. *Hestina nama* (Nymphalidae)

Forest Type: *Quercus semicarpifolia, Rhus succidenia, Ribes acuminatum, Alnus nepalensis*
Total species record: 21 species
Rare species:

1. *Syntarucus plinius* (Lycaenidae)
2. *Everes argiades diporides* (Lycaenidae)
3. *E. hugelii* (Lycaenidae)
4. *Creon cleobis* (Lycaenidae)
5. *Rapala nissa nissa* (Lycaenidae)
6. *Heliophotus tamu tamu* (Lycaenidae)
7. *Byasa alcinous pembertoni* (Papilionidae)
8. *Mycalesis suavolens* (Satyridae)
9. *Pelopidas sinensis* (Hesperiidae)
10. *Taractrocera danna* (Hesperiidae)

Forest Type: *Quercus semicarpifolia, Alnus nepalensis, Berberis chitria, Rhododendron arboreum.*
Total species record: 4 species
Rare species:

1. *Dodona egeon egeon* (Nemeobiidae)
2. *Borbo cinnara cinnara* (Hesperiidae)

Mixed broadleaf conifer zone
Elevation 3000-3500 m
Forest Type: *Rhododendron arboreum, Tsuga dumosa, Alnus nepalensis, Abies spectabilis.*
Total species record: 7 species
Rare species:

1. *Atrophaneura latrellei latrellei* (Papilionidae)
2. *Neptis ananta ochracea* (Nymphalidae)

Forest Type: *Tsuga dumosa, Abies spectabilis, Betula alnoides, Hippohae selecifolia, Rhododendron arboreum.*
Total species record: 23 species
Rare species:

1. *Dodona dipoea dipoea* (Nemeobiidae)
2. *Heliophoros tamu tamu* (Lycaenidae)
3. *Albulina lehna* (Lycaenidae)
4. *Creon cleobis* (Lycaenidae)
5. *Esakiozephyrus mandara dohertyi* (Lycaenidae)
6. *Chryosozephyrus sikkimensis* (Lycaenidae)
7. *Neptis radha radha* (Nymphalidae)

8. *Lethe baladeva baladeva* (Satyridae)

9. *L. insana dinarbus* (Satyridae)

10. *L. rohria rohria* (Satyridae)

11. Aulocera saraswatti saraswatti (Satyridae)

Forest Type: *Rhus succidenia, Taxus baccata, Leucana leucocephala, Quercus semicarpifolia.*
Total species record: 16 species
Rare species:

1. *Deudoryx epijarbus ancus* (Lycaenidae)

2. *Chliaria kina* (Lycaenidae)

3. *Panchala birmana birmana* (Lycaenidae)

4. *Kaniska canace canace* (Nymphalidae)

5. *Mycalesis heri* (Satyridae)

6. *Lethe rohria rohria* (Satyridae)

7. *Tagiades menaka menaka* (Hesperiidae)

8. *Borbo cinnara cinnara* (Hesperiidae)

Forest Type: *Alnus nepalensis, Berberis sp., Ilex dipyrena, Salix denticulata, Rhododendron arboreum.*
Total species record: 18 species
Rare species:

1. *Parnassius hardwickei hardwickei* (Papilionidae)

2. *Everes hugelii hugelii* (Satyridae)

3. *Aulocera loha* (Satyridae)

4. *A. brahminus brahminus* (Satyridae)

5. *A. saraswatti saraswatti* (Satyridae)

6. *A. padma padma* (Satyridae)

7. *Zophoessa maitrya maitrya* (Satyridae)

Forest Type: *Abies spectabilis, Quercus semicarpifolia, Picea smithiana, Tsuga dumosa, Berberis macrosepala, Rhododendron sp.*
Total species record: 18 species
Rare species:

1. *Parnassius hardwickei hardwickei* (Papilionidae)

2. *Argyneus hyperbius hyperbius* (Nymphalidae)

3. *Childrena childreni* (Nymphalidae)

4. *Aulocera padma padma* (Satyridae)

5. *Zophoessa jalaurida jalaurida* (Satyridae)

Forest Type: *Rhododendron setosum, R. lepidatum, Abies spectabilis, Tsuga dumosa, Betula utilis, Astragalus pychorhizus, Quercus semicarpifolia*
Total species record: 11 species
Rare species:

1. *Colias erate glicia* (Pieridae)
2. *Colias fieldii fieldii* (Pieridae)
3. *Celatoxia marginata marginata* (Lycaenidae)
4. *Potanthus pseudomaesa clio* (Hespriidae)

Sub-alpine shrub zone
Elevation 3500- 4300 m
Forest Type: *Betula utilis, Rhododendron lepidatum, Rhododendron anthopogan, Rhododendron* setosum, Berberis macrosepala, Juniperus recurva, Larix sp.
Total species record: 10 species
Rare species:

1. *Parnassius hardwickei hardwickei* (Papilionidae)
2. *P. epaphus epaphus* (Papilionidae)
3. *Kukenthalia gemmata* (Nymphalidae)
4. *Aulocera swaha* (Satyridae)

Vegetation Type: *Shrubby vegetation Rhododendron setosum, Rhododendron campanulatum, Cotoneaster microphyllus, Hippophae rhamniodes*
Total species record: 2 species

1. *Parnassius epaphus epaphus* (Papilionidae)
2. *Issoria issaea issaea* (Nymphalidae)

Uncommon and rare butterflies of lowland Nepal (<1000 m):i.e., the Lowland *sal*and Terai zones (from Khanal 2008)

PAPILIONIDAE

- *Menelaides nephelus chaon*
- *Iliades memnon*
- *Euploeopsis clytia f. dissimilis* (rare)
- *Deoris nomius*

PIERIDAE

- *Eurema laeta*
- *Catopsilia pomona f. catilla* (rare)
- *Cepora nerissa phryne*

LYCAENIDAE

- *Heliophorus sena*

- Chliar*ia othona*
- *Zizeena otis otis*
- *Euchrysops cnejus*
- *Chilades pandava* (rare)
- *Tarucus callinara* (rare)
- *Curetis dentate* (rare)
- *Curetis bulis*
- *Rapala manea schistacea* (rare)
- *Catochrysops strabo*
- *Spindasis elima uniformis* (rare)
- *Horaga onyx* (rare)
- *Rapala nissa* (rare)
- *Remelana jang*ala (rare)

NYMPHALIDAE

- Cyrestis t*hyodamus*
- *Kallima ina*chus

SATYRIDAE

- Ypthima *baldus baldus*
- *Ypthima singala*
- *Ypthima huebneri*
- *Elymn*ias hypermnestra

DANAIDAE

- *Tirmala septentrionis*

HESPERIIDAE

- Thoress*a aina* (rare)
- *Badamia exclamationis*

Appendix 7. Endemic plants from CHAL and TAL.

(Data from Shrestha and Joshi, 1996)

FAMILY	SPECIES	ALTITUDE RANGE (m)
Orchidaceae	*Oreorchis porphyranthus*	3100-3800
Zingiberaceae	*Roscoea nepalensis*	2450-3050
	Iris staintonii	3500
Eriocaulaceae	*Eriocaulon staintonii*	700-1800
Cyperaceae	*Carex himalaica*	3500-4200
	Carex rufulistolon	3100
	Kobresia fissiglumis	3650-3950
	Kobresia gandakiensis	1200-2000
	Kobresia mallae	3550-4570
Graminae	*Poa kanaii*	4600-5200
	Poa mustangensis	4800-4900
	Stipa staintonii	3200-4000
Ranunculaceae	*Aconitum dhwojii*	4500-4800
	Aconitum nepalense	4000-6000
	Aconitum williamsii	3300
	Clematis alternate	1470-3000
	Clematis bracteolate	3700
	Delphinium himalayai	2400-4500
Berberidaceae	*Berberis mucrifolia*	2700-4200
Papaveraceae	*Corydalis megacalyx*	3600-4570
	Mecanopsis regia	2700-4600
	Mecanopsis taylorii	3600-4570
Cruciferae	*Staintoniella nepalensis*	4900-5800
Flacourtiaceae	*Homalium napalensis*	700-4500
Caryophyllaceae	*Arenaria mukerjeeana*	3200-4400
	Arenaria paramelanandra	4200-5200
	Silene fissicalyx	4100-4600
	Silene helleboriflora	3000-5500

FAMILY	SPECIES	ALTITUDE RANGE (m)
	Silene holosteifolia	2700-3600
	Silene stellarifolia	1700
	Silene vautierae	3500-5000
	Stellaria congestiflora	4000-4700
Balsaminaceae	*Impatiens scullyi*	1800-2630
Rutaceae	*Ruta cordata*	4500
Leguminoseae	*Astralagus nakaoi*	3800
	Caragana campanulata	3200-3500
	Oxytropis graminetorum	3800-4300
	Oxytropis nepalensis	3500-4100
Rosaceae	*Prunus himalaica*	3900
Saxifragaceae	*Saxifraga alpigena*	3450-4250
	Saxifraga cinerea	2700-3250
	Saxifraga excellens	3600-4700
	Saxifraga hypostoma	3900-5250
	Saxifraga lowndesii	3800-4100
	Saxifraga namdoensis	4500
	Saxifraga neopropagulifera	4500-5600
	Saxifraga poluninana	2250-3500
	Saxifraga staintonii	4800
	Saxifraga williamsii	4000-4800
Crassulaceae	*Rhodiola amabilis*	2300-3900
	Rhodiola nepalica	3700-4500
	Rosularia marnieri	3500-4300
Onagraceae	*Epilobium brevisquamatum*	3200
	Epilobium staintonii	3600-3650
Umbelliferae	*Heracleum lallii*	3000-4400
Compositae	*Artemisia tukuchaensis*	3150-3700
	Cicerbita nepalensis	1600-3000
	Cirsium nishiokae	2350-4000

FAMILY	SPECIES	ALTITUDE RANGE (m)
	Cremanthodium nepalensis	2800-4900
	Cremanthodium purpureifolium	3600-4900
	Crepis himalaica	3300
	Leontopodium makianum	4000
	Saussurea linearifolia	3300-4600
	Saussurea spicata	4000-5500
	Taraxacum staintonii	2700-2900
	Codonopsis nepalensis	3200
Ericaceae	*Rhododendron lowndesii*	2450-4500
Primulaceae	*Primula sharmae*	2500-5300
	Primula wigramiana	3600-5200
Asclepiadaceae	*Ceropegia meleagris*	2000-2500
Gentianaceae	*Swertia gracilescens*	2000-3700
Boraginaceae	*Arnebia nepalensis*	4100
	Maharanga wallichiana	2400-3600
Scrophulariaceae	*Pedicularis annapurnensis*	4150-4250
	Pedicularis anserantha	3600-4000
	Pedicularis breviscaposa	3000-4000
	Pedicularis chamissonoides	3800
	Pedicularis elevatogaleata	3800-4600
	Pedicularis poluninii	4400
	Pedicularis sectifolia	3000-5600
	Pedicularis wallichii	4000-4700
Acanthaceae	*Dossifluga cuneata*	2400-2500
Verbanaceae	*Caryopteris nepalensis*	900-2100
	Lamium tuberosum	3600-4800
	Micromeria nepalensis	1900-3600
Polygonaceae	*Fallopia filipes*	1900-2900
Elaeagnaceae	*Elaeagnus tricholepis*	1600-2500
Salicaceae	*Salix eriostachya*	3200-4500

Appendix 8. Threatened Plants from CHAL and TAL.

(Data from Shrestha and Joshi)

FAMILY	SPECIES	ALTITUDE RANGE (m)
Capparaceae	*Crateva unilocularis*	100-1800
Leguminosae	*Acacia catechu*	200-1400
	Butea monospermus	150-1200
	Dalbergia latifolia	300-1000
Palmae	*Wallichia densiflora*	250-1400
Liliaceae	*Gloriosa superba*	200-2200
	Lilium wallichianum	1100-2400
	Paris polyphylla	1800-3500
Gnetaceae	*Gnetum montanum*	300-1800
Cycadaceae	*Cycas pectinata*	300-660
Asclepiadaceae	*Hoya arnottiana*	300-950
	Tylophora belostemma	600-1200
Dioscoreaceae	*Dioscorea deltoidea*	450-3100
	Dioscorea prazeri	910-1600
Apocynaceae	*Alstonia neriifolia*	500-1200
	Alstonia scolaris	100-1270
	Beaumontia grandiflora	150-1400
Magnoliaceae	*Michelia champaca*	600-1300
	Michelia kisopa	1400-2800
	Talauma hodgsonii	900-1800
Elaeocarpaceae	*Elaeocarpus sphaericus*	650-1700
Podocarpaceae	*Podocarpus neriifolius*	850-1530
Saxifragaceae	*Bergenia ciliata*	900-4300
Passifloraceae	*Passiflora napalensis*	1000-2400
Pinaceae	*Larix griffithiana*	1100-4000
Anacardaceae	*Choerospondias axillaris*	1200-1500
Gentianaceae	*Swertia chirayita*	1500-2500
Fagaceae	*Lithocarpus fenestrata*	1500-2000

FAMILY	SPECIES	ALTITUDE RANGE (m)
Boraginaceae	*Maharanga bicolor*	1700-3600
	Maharanga emodi	2200-4500
Ulmaceae	*Ulmus wallichiana*	1800-3000
Betulaceae	*Alnus nitida*	1800-2800
Ranunculaceae	*Aconitum ferox*	2100-3800
	Aconitum gammiei	3300-4300
	Acconitum heterophyllum	2400-4000
	Acconitum laciniatum	2800-4600
	Acconitum spicatum	1800-4300
Aralicaceae	*Helwingia himalaica*	2100-2700
Rosaceae	*Prunus carmesina*	2300-2600
Araceae	*Arisaema utile*	2400-4300
Berberidaceae	*Podophyllum hexandrum*	2400-4500
Amaryllidaceae	*Allium przewalskianum*	2700-4300
Cruciferae	*Megacarpaea polyandra*	2700-4500
Valerianaceae	*Nardostachys grandiflora*	3200-5300
Plumbaginaceae	*Ceratostigma ulicinum*	3500-4000
Scrophulariaceae	*Piorhiza scrophulriiflora*	3500-4800
Polygonaceae	*Rheum nobile*	3600-5000