Climate-change Impacts on the Biodiversity

of the Terai Arc Landscape and the Chitwan-Annapurna Landscape

By

Gokarna Jung Thapa

Eric Wikramanayake

Jessica Forrest

2013

Climate-change Impacts on the Biodiversity of the Terai Arc Landscape and the Chitwan-Annapurna Landscape

By

Gokarna Jung Thapa[1]

Eric Wikramanayake[2]

Jessica Forrest[2]

2013

[1] WWF Nepal Program, Baluwatar, Kathmandu, NEPAL

[2] Conservation Science Program, WWF US, Washington DC, USA

Published by
WWF Nepal, Hariyo Ban Program
This publication is also available in www.wwfnepal.org/publications

PO Box: 7660
Baluwatar, Kathmandu, Nepal
T: +977 1 4434820, F: +977 1 4438458
hariyobanprogram@wwfnepal.org, www.wwfnepal.org/hariyobanprogram

Authors

This report was prepared by:
Gokarna Jung Thapa, WWF Nepal Program, Baluwatar, Kathmandu, Nepal
Eric Wikramanayake, Conservation Science Program, WWF US, Washington DC, USA
Jessica Forrest, Conservation Science Program, WWF US, Washington DC, USA

Disclaimer

Hariyo Ban Publication Number: Report 030

ACKNOWLEDGEMENTS

We want to thank several individuals and organizations for assisting and supporting this analysis.

Special thanks to organizations for providing helpful data and information. We are grateful towards Government of Nepal and DANIDA Tree Improvement and Silviculture Component (TISC) for Ecological Vegetation data which was revised by Tirtha B. Shrestha and team.

We also thank WorldClim (http://www.worldclim.org) for providing easily accessible web data on current scenario. Similarly, we thank U.S. Geological Survey (http://srtm.usgs.gov/) for SRTM data and International Centre for Tropical Agriculture (CIAT) and the CGIAR Research Program on Climate Change, Agriculture and Food Security (CCAFS) (http://www.ccafs-climate.org/data/) for future scenario data. We are also grateful towards ICIMOD for providing the digital data.

We are also thankful towards Dr. Shant Raj Jnawali, Dr. Sunil Regmi, Judy Oglethorpe, Ramesh Adhikari, Ugan Manandhar, and Santosh Nepal for helpful comments and review of early versions of the document, as well as for the productive discussions that helped to shape the analysis. Thank you to Ryan Bartlett and Sarah Freeman from WWF US as well. We appreciate the help of Anil Manandhar, Pankaj Bajracharya, Kamal Thapa, Dhana Rai and Dr. Narendra Pradhan in shaping this analysis. Special thanks to Dr. Ghana Shyam Gurung for his encouragement throughout this project.

Lastly, thank you to United States Agency for International Development (USAID) for funding this analysis through the Hariyo Ban Program.

Gokarna Jung Thapa, WWF Nepal Program
Eric Wikramanayake, Conservation Science Program, WWF US
Jessica Forrest, Conservation Science Program, WWF US

ABBREVIATIONS AND ACRONYMS

ACA	Annapurna Conservation Area
CHAL	Chitwan-Annapurna Landscape
CR	Critically Endangered
GCMs	General Circulation Models
GHG	Green House Gas
GLOF	glacial lake outburst flood
HadCM3	Hadley Centre Coupled Model version 3
IPCC	Intergovernmental Panel on Climate Change
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

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 WWF's portfolio of Global 200 ecoregions. 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 projections 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. The results 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. Relatively large (>500 ha) patches of contiguous forests will remain as climate 'macro-refugia' along the montane regions of the CHAL, and should be conserved because of their high biodiversity values. Further degradation from short-term anthropogenic drivers should be prevented. Smaller patches of resilient forests in the lower, subtropical zone should also be identified and conserved, with strategic restoration and conservation of vulnerable areas to maintain north-south connectivity for ecosystem functions and services.

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 elevational gradient, overlaps of several biogeographic barriers, and regional monsoonal precipitation.[1] The distribution of the region's biodiversity has been mapped as ecoregions that are generally directed along the longitudinal axis of the mountain range,[2] 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 a range of forest types between and along the steep altitudinal cline, from <300 m to over 4000 m. The vegetation that comprises these distinct ecoregions is the consequence of the interactions of elevation, precipitation, temperature, and seasonality.[3,4,5,6]

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.

In Nepal, the forests and grasslands in these ecoregions are heavily converted, fragmented and degraded.[7] Consequently, many species and ecological communities are under threat from local extinction. Particularly vulnerable are the larger species such as tiger (*Panthera tigris*), Asian

---

[1] Wikramanayake, E.D., C. Carpenter, H. Strand, and M. McKnight. 2001. Ecoregion-Based Conservation in the Eastern Himalaya. Identifying Important Areas for Biodiversity Conservation. World Wildlife Fund (WWF) and Center for Integrated Mountain Development (ICIMOD).

[2] Wikramanayake, E.D., E. Dinerstein, C. Loucks, D. Olson, J. Morrison, J. Lamoreux, M. McKnight, and P. Hedao. 2001. Terrestrial ecoregions of the Indo-Pacific: a conservation assessment. Island Press: Washington, D.C.

[3] Ohsawa, M. 1995. Latitudinal comparison of altitudinal changes in forest structure, leaf-type, and species richness in humid monsoon Asia. Vegetatio. 121:3-10

4 Ohsawa,M. 1990. An interpretation of latitudinal patterns of forest limits in south and east Asian mountains. Journal of Ecology. 78:326-339

[5] Jobbagy, E.B. and R.B. Jackson. 2000. Global controls of forest line elevation in the northern and southern hemispheres. Global Ecology and Biogeography. 9:253-268.

[6] Körner, C. 1998. A re-assessment of high elevation treeline positions and their explanation. Oecologia. 115:445-459

[7] Wikramanayake, E.D., E. Dinerstein, C. Loucks, D. Olson, J. Morrison, J. Lamoreux, M. McKnight, and P. Hedao. 2001. Terrestrial ecoregions of the Indo-Pacific: a conservation assessment. Island Press: Washington, D.C.

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 the 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[8] with very small range distributions whose habitat can be completely lost from forest loss and degradation.

Importantly, ecosystem degradation also affects ecosystem function of biological communities and ecological services that also support human communities. The livelihoods, lives, and local and national economic investments in the Himalaya are also strongly dependent on sustained provision of water.[9] A clean environment that minimizes diseases, supports pollination of crops and provides forest products are some other ecosystem services that are vital for human communities, and loss or degradation of this natural capital can have serious repercussions for human well-being and economic and social stability.[10,11]

In recent years, global climate change been recognized as a significant driver of ecological change.[12,13] The Himalayas are no exception. Assessments show that the eastern Himalayan terrestrial ecoregions are vulnerable to global climate change.[14,15,16] The IPCC projects that the

---

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

[9] Eriksson, M., X. Jianchu, A.B. Shrestha, R.A. Vaidya, S. Nepal, K. Sandström. 2009. The changing Himalayas – Impact of climate change on water resources and livelihoods in the Greater Himalayas. ICIMOD publ.

[10] Ehrlich, P.R., P.M. Kareiva, and G.C. Daily. 2012. Securing natural capital and expanding equity to rescale civilization. Nature 486:68–73.

[11] Foley, J. A. *et al.* 2005. Global consequences of land use. Science. 309:570–4.

[12] IPCC, 2007. Climate Change 2007: Synthesis Report. Contribution of Working Groups I, II and III to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change [Core Writing Team, Pachauri, R.K and Reisinger, A.(eds.)]. IPCC, Geneva, Switzerland,104 pp

[13] Parmesan, C. 2006. Ecological and evolutionary responses to recent climate change. Ann. Rev. Ecol. Evol. Syst. 37:637–69

[14] Beaumont, L. J., A. Pitman, S. Perkins, N.E. Zimmermann, and N.G. Yoccoz. 2010. Impacts of climate change on the world's most exceptional ecoregions. (2010).doi:10.1073/pnas.1007217108
[15] Li, J. *et al.* 2013. Global Priority Conservation Areas in the Face of 21st Century Climate Change. PLoS ONE 8, e54839 (2013).

[16] Shrestha, U. B., S., Gautam, and K.S. Bawa. 2012. Widespread climate change in the Himalayas and associated changes in local ecosystems. PloS one 7, e36741 (2012).

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 comparison with historical averages from 1980-1999, while annual precipitation is expected to increase throughout this region as well. [17] More recent assessments, however, indicate that temperature and precipitation changes will be greater than the upper bounds predicted by the IPCC.[18] 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.[19]

PROJECTED CLIMATE CHANGE TRENDS IN NEPAL

Nepal's National Adaptation Programme of Action (NAPA)[20] documents temperature and precipitation trends and provides national-scale climate projections (text below).

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.[21] Himalayan glacier

[17] Meehl, G.A., Stocker, T.F., Collins, W.D., Friedlingstein, P., Gaye, A.T., Gregory, J.M., Kitoh, A., Knutti, R., Murphy, J.M., Noda, A., Raper, S.C.B., Watterson, I.G., Weaver, A.J., Zhao, Z.C. 2007. Global climate projections. In: Solomon, S., Qin, D., Manning, M., Chen, Z., Marquis, M., Averyt, K.B., Tignor, M., Miller, H.L. (Eds.), Climate Change 2007: The Physical Science Basis. Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA, pp. 747–845.

[18] Shrestha, U. B., S., Gautam, and K.S. Bawa. 2012. Widespread climate change in the Himalayas and associated changes in local ecosystems. PloS one 7, e3674.

[19] Xu, J. *et al.* 2009. The melting Himalayas: cascading effects of climate change on water, biodiversity, and livelihoods. Conservation Biology. 23:520–30.

[20] Ministry of Environment (MoE).2010. National Adaptation Programme of Action. Kathmandu, Nepal.

[21] Ministry of Environment (MoE).2010. National Adaptation Programme of Action. Kathmandu, Nepal.

melt and retreat have also been documented, with 18 glacial lake outburst flood (GLOF) events recorded in Nepal between 1936 and 2000.[22]

Projected climate change

The NAPA reports climate projections conducted by the Organization for Economic Cooperation and Development (OECD)[23] and the Nepal Climate Vulnerability Study Team (NCVST)[24]. The OECD analysis used GCMs with the SRES (Special Report on Emissions Scenarios) 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 GCM 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 are similar to those of the IPCC that predict a warming trend with variable, unpredictable and extreme weather events (floods and droughts), increase in rain during the wet season but the mid-hills will experience less rain during this period (NAPA).

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

---

[22] Callot, B., Harjung, J., Löcht, J. Van De and Unterköfler, R. 2009. Climate Change Himalayas. pp 1–21.

[23] Organization for Economic Cooperation and Development. (2003). Development And Climate Change In Nepal: Focus On Water Resources and Hydropower. In: NAPA, 2010.

[24] NCVST. 2009. Vulnerability Through the Eyes of Vulnerable: Climate Change Induced Uncertainties and Nepal's Development Predicaments. Institute for Social and Environmental Transition-Nepal (ISET-N), Nepal Climate Vulnerability Study Team (NCVST) Kathmandu National Disasters Report. UNDP-Nepal. In: NAPA, 2010

conservation plans and ‘no-regrets’ strategies.[25] 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.[26,27] While the criticisms are justified, bioclimatic models can, however, provide much-needed guidelines for climate-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.[28,29,30]

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 resultant outputs were used to assess the impact on species of conservation concern[31] and other biodiversity.[32]

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).

---

[25] Hannah, L.G., F. Midgley, T. Lovejoy, W.J. Bonds, M. Bush, J.C. Lovett, D. Scott, and F I. Woodward. 2002. Conservation of Biodiversity in a Changing Climate. Conservation Biology 16:264–268.

[26] Lawler, J.J., D. White, R.P. Neilson, and A.R Blaustein. 2006. Predicting climate-induced range shifts: model differences and model reliability. Global Change Biology 12:1568–1584.

[27] Heikkinen, R.K. *et al.* 2006. Methods and uncertainties in bioclimatic envelope modelling under climate change. Progress in Physical Geography 6: 1–27.

[28] Hannah, L.G., F. Midgley, T. Lovejoy, W.J. Bonds, M. Bush, J.C. Lovett, D. Scott, and F I. Woodward. 2002. Conservation of Biodiversity in a Changing Climate. Conservation Biology 16:264–268.

[29] Pearson, R.G., and T.P. Dawson. 2003. Predicting the impacts of climate change on the distribution of species: are bioclimate envelope models useful? Global Ecology and Biogeography 12:361–371.

[30] Keith, D., H.R. Akçakaya, W. Thuiller, G.F. Midgley, R.G. Pearson, S.J. Phillips, H.M. Regan, M.B. Araújo, T.G. Rebelo. 2008. Predicting extinction risks under climate change: coupling stochastic population models with dynamic bioclimatic habitat models. Biology Letters 4:560–3.

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

[32] 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.

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 for 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 only be used as a touchstone to guide the integration of output predictions based on climate change related impacts. These outputs 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 institutionalized for continued analyses, but that the models should be updated as improved bioclimatic analyses evolve.

THE LANDSCAPES

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.[33,34] 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 sequestered within the protected areas that were too small 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 sequestered populations, and thus maintain 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. The conservation interventions for these charismatic mega vertebrates therefore 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 flood plains at the base of the Churia hill range (Figure 1).

The major vegetation types along the riverbanks and flood plains of the TAL are tall grass and *sisoo*-dominated (*Dalbergia sisoo*) forests. The lowlands away from the rivers are *sal* dominated forests, sometimes occurring in mono-stands. The flood plains 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

[33] MFSC. 2004. Terai Arc Landscape – Nepal. Strategic Plan 2004-2014. Broad strategy document. Ministry of Forests and Soil Conservation. His Majesty's Government of Nepal, Kathmandu, Nepal

[34] Wikramanayake, E., A. Manandhar, S. Bajimaya, S. Nepal, G. Thapa, K. Thapa. 2010. The Terai Arc Landscape: A tiger conservation success story in a human-dominated landscape. In R. Tilson and P. Nyhus, eds. Tigers of the World (2nd edition): The Science, Politics, and Conservation of Panthera tigris. Elsevier/Academic Press. Pages 161-172

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. Sal forests grow on the steeper, dry slopes. During the winter, when river flows are low, the dry beds of braided rivers and nearby floodplains support near mono-specific stands of *Saccharum spontaneum* grasses that sprout soon after the flows and floods recede. Thus, the Terai grasslands and woodlands are maintained by annual disturbance events.[35]

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**	**X**		**X**		**X**
Rhinoceros	**TAL**			**X**	**X**	
Snow leopard	**CHAL**	**X**	**X**	**X**	**X**	**X**
Red panda	**CHAL**		**X**		**X**	
Musk Deer	**CHAL**		**X**		**X**	
Altitudinal migrant birds[1]	**CHAL**	**X**		**X**	**X**	**X**
Hornbills, pheasants, tragopans	**CHAL**	**X**	**X**	**X**	**X**	**X**
Gharial	**TAL**		**X**		**X**	
Mahseer	**TAL/CHAL**	**X**	**X**	**X**	**X**	**X**

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, and also globally renowned for their biodiversity. The linkage was first identified during a WWF-

[35] Seidensticker, J., E. Dinerstein, S. P. Goyal, B. Gurung, A. Harihar, A.J.T. Johnsingh, A. Manandhar, C. McDougal, B. Pandav, M. Shrestha, J.L. D. Smith, M. Sunquist, E. Wikramanayake. 2010. Tiger range collapse and recovery at the base of the Himalayas. In: David Macdonald, Andrew Loveridge, eds. The Biology and Conservation of Wild Felids. Oxford University Press. 305–323.

supported initiative to develop a conservation vision for the Eastern Himalayan region, and covers the whole of the Gandaki river basin in Nepal.[36] The altitudinal range from ~200 m to > 2200 m includes the Terai Duar Savanna and Grasslands, Himalayan Subtropical Broadleaf Forests, Himalayan Subtropical Pine Forests, Eastern Himalayan Temperate Broadleaf Forests, Eastern Himalayan Subalpine Conifer Forests, Eastern Himalayan Alpine Shrub and Meadows, Western Himalayan Temperate Broadleaf Forests, Western Himalayan Subalpine Conifer Forests, and Western Himalayan Alpine Shrub and Meadows ecoregions (Figure 2), which is an indication of the biodiversity value of this landscape. The deep Gandaki river gorge represents a biogeographic barrier at higher elevations. Because the CHAL straddles this biogeographic barrier, it includes sections of both western and eastern ecoregions and the biodiversity restricted to each. Thus, the linkage has a diverse biodiversity along the vertical and horizontal axes.

[36] Basnet, K., P. Shrestha, K.A. Shah, and P. Ghimere. 2000. Biodiversity assessment of corridors linking Annapurna Conservation Area and Chitwan National Park-Parsa Wildlife Reserve. In: Chitwan Annapurna Linkage. Biodiversity Assessment and Conservation Planning. WWF Nepal Program.

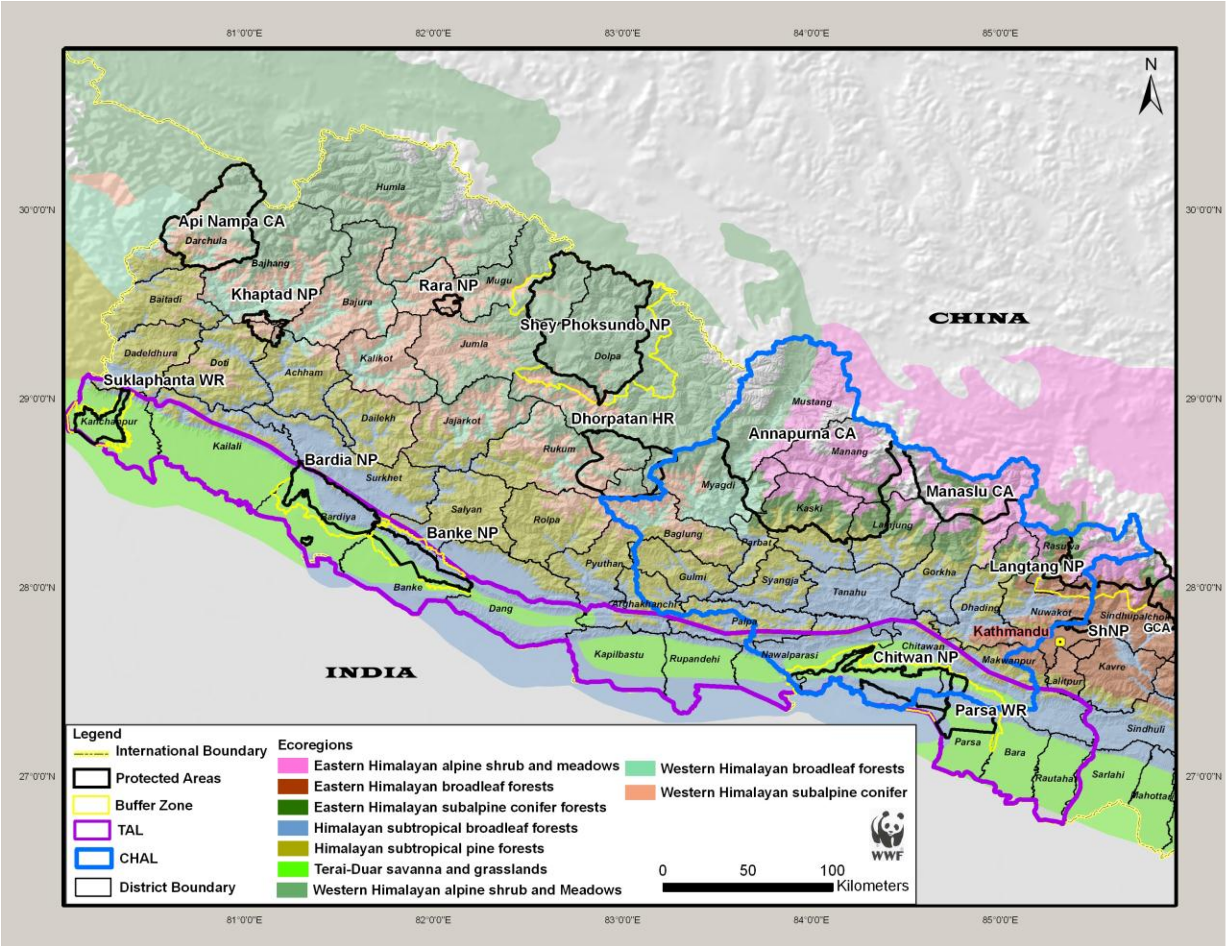


Figure 2. Ecoregions represented in the TAL and CHAL. The Terai Duar Savanna and Grasslands, and the combined Eastern Himalayan Temperate Broadleaf Forests and Eastern Himalayan Subalpine Conifer Forests represent three Global 200 ecoregions with biodiversity of global importance.

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 ecological services and natural capital benefits. The rivers in the Gandaki basin, notably the Kali Gandaki, Marsyangdi, Seti, Trishuli and Madi, have existing and/or planned hydropower investments. They also support the water requirements of the local and downstream communities. Forested watersheds are therefore important to sustain human livelihoods, lives, and economic investments by regulating river flows, water runoff, and preventing 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 have become highly fragmented, conservation of the remaining fragments and strategic restoration to improve connectivity is therefore important to support the ecological requirements of these species. Continued fragmentation can result in species population declines, further degradation of ecological processes and functions, 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.

METHODS

We used the IPCC A2A GHG scenario[37] to project the potential future distributions of 8 ecological habitat zones modified from the vegetation zone map prepared by the Department of Forests.[38] 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.[39,40,41] Regardless of

[37] IPCC (Intergovernmental Panel on Climate Change), 2007. Climate change 2007: the physical science basis, in: Solomon, S., Qin, D., Manning, M., Chen, Z., Marquis, M., Averyt, K.B., Tignor, M., Miller, H.L. (Eds.), Contribution of Working Group I to the Fourth assessment report of the Intergovernmental Panel on Climate Change. Cambridge University Press, Cambridge, United Kingdom. Pp: 235–336.

[38] 2002, Forest and Vegetation Types of Nepal. TISC Document Series No. 105. Dept of Forest, HMG/NARMSAP, International Year of Mountain Publication, Nepal.

[39] Raupach, M.R., Marland, G., Ciais, P., Le Quere, C., Canadell, J.G., Klepper, G., Field, C.B., 2007. Global and regional drivers of accelerating CO2 emissions. Proceedings of the National Academy of Science 104, 10288–10293. http://dx.doi.org/10.1073/pnas.0700609104.

[40] Hansen, J., M. Sato, and R. Ruedy. 2012. Perception of climate change. Proceedings of the National Academy of Sciences of the United States of America 109:2415–23.

[41] Turn down the heat. 2012. A report for the World Bank by the Potsdam Institute for Climate Impact Research and Climate Analytics.

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 niches and future niches under the high 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 several alternative scenarios should be considered and evaluated against other knowledge.

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

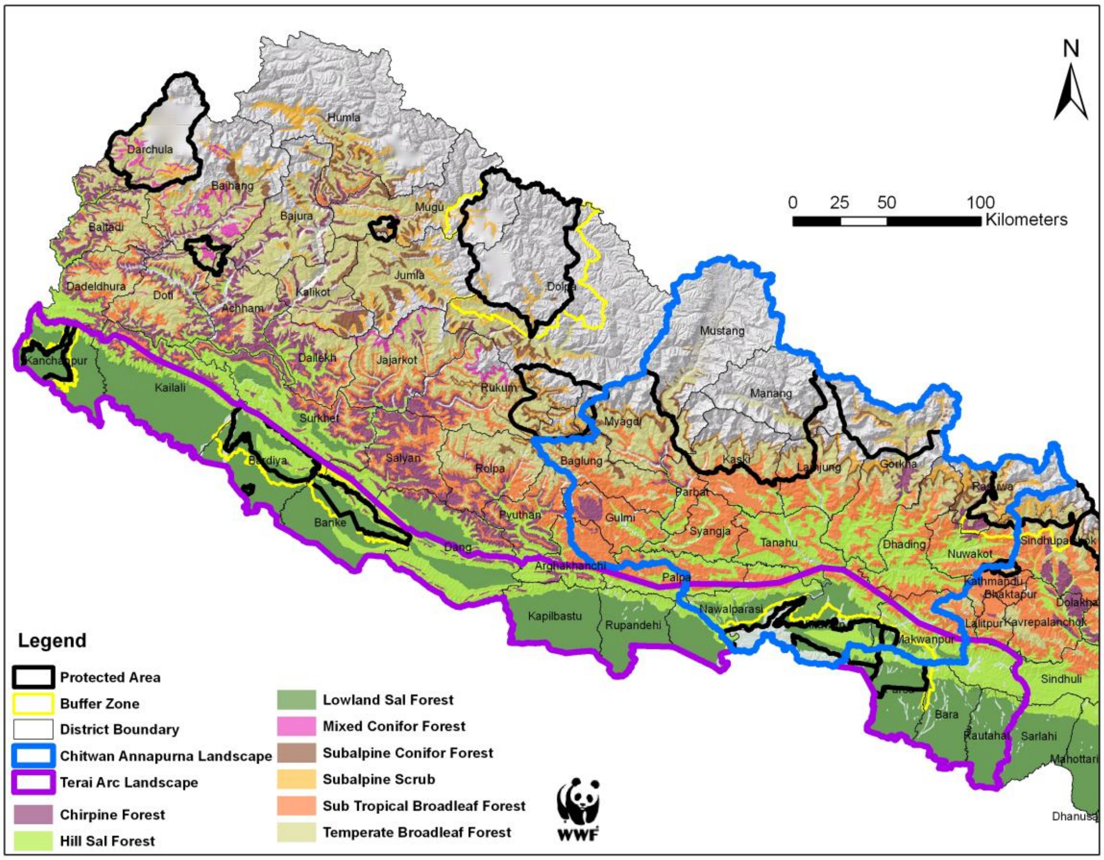


Figure 3. Potential distribution of the eight broad vegetation types. See Appendix 1 for details of the reclassification and relationships of the vegetation types with forest types in the Forest Department map.

http://climatechange.worldbank.org/sites/default/files/Turn_Down_the_heat_Why_a_4_degree_centrigrade_warmer_world_must_be_avoided.pdf downloaded Feb 2013.

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. While this map has its own limitations, we believed 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 ecological/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) Chir Pine forest, 4) Subtropical Broadleaf forest, 5) Temperate Broadleaf forest, 6) Mixed Conifer-Broadleaf forest, 7) Subalpine Conifer forest, and 8) Subalpine shrub (Figure 3). We then generated more than 1,000 random observation points for the each vegetation type and entered these into Maxent along with 19 WorldClim bioclimatic variables representing historical climate for the years 1950-2000 .[42,43,44] WorldClim is a global climate dataset representing historical monthly averages, minimums, and maximums in temperature and average monthly

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

[42] Hijmans, R.J., S.E. Cameron, J.L. Parra, P.G. Jones, and A. Jarvis. 2005. Very high resolution interpolated climate surfaces for global land areas. International Journal of Climatology 25:1965-1978

[43] Hijmans, R.J., and C.H. Graham. 2006. The ability of climate envelope models to predict the effect of climate change on species distributions. Global Change Biology 12:2272-2281. doi: 10.1111/j.1365-2486.2006.01256.x

[44] Phillipps, S.J., R.P. Anderson, and R.E. Shapire. 2006. Maximum entropy modeling of species geographic distributions. Ecological Modelling 190:231-259.

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.

Maxent was used to project the current and future distributions of 8 vegetation types. The heuristic estimates of relative contributions of the 19 bioclimatic environmental variables to the Maxent model of habitat types under the 2020, 2050, and 2080 projections are provided in Appendices 2-4.

Future distributions represent equilibrium climate for the years 2020, 2050, and 2080 under an A2A GHG emission scenario projected by a downscaled Hadley Centre Coupled Model version 3 (HadCM3) General Circulation Model (GCM).[45] The HadCM3 GCM[46] 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.[47,48,49] Only 3 GCMs predict that annual precipitation will decrease under future climate change under an A2 scenario.

---

[45] Ramirez-Villegas, J. and Jarvis, A. 2010. Downscaling Global Circulation Model Outputs: The Delta Method Decision and Policy Analysis Working Paper No. 1. Available at: http://www.ccafs-climate.org/downloads/docs/Downscaling-WP-01.pdf. Accessed on April 29, 2013.

[46] Mitchell, T. D., Carter, T.R., Jones, P.D., Hulme, M., New, M., 2004. A comprehensive set of high-resolution grids of monthly climate for Europe and the globe: the observed record (1901–2000) and 16 scenarios (2001–2100). Tyndall Centre for Climate Change Research, University of East Anglia, UK.

[47] Meehl, G. A., Covey, C., Delworth, T., Latif, M., McAvaney, B., Mitchell, J.F.B., Stouffer, R.J., Taylor, K. E., 2007. The WCRP CMIP3 multi-model dataset: A new era in climate change research. Bulletin of the American Meteorological Society 88, 1383-1394.

[48] Mitchell, T. D., Carter, T.R., Jones, P.D., Hulme, M., New, M., 2004. A comprehensive set of high-resolution grids of monthly climate for Europe and the globe: the observed record (1901–2000) and 16 scenarios (2001–2100). Tyndall Centre for Climate Change Research, University of East Anglia, UK.

[49] Zganjar, C., Girvetz, E., Raber, G., 2009. ClimateWizard. The Nature Conservancy, University of Washington, and University of Southern Mississippi . Washington, DC. USA. Available from http://www.climatewizard.org (accessed January 2010).

The vegetation distribution map for the 2020 projection was clipped with the current (2010) forest cover map[50] to select the resilient forest patches of each vegetation type (Figure 4). The 'resilient' 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 2020 resilient vegetation map was then used as a template to clip the 2050 vegetation distribution and select the resilient patches of each vegetation type (Figure 5). Finally, the 2050 coverage was used as a template to identify the resilient patches in 2080 (Figure 6). The process is outlined in Figure 7.

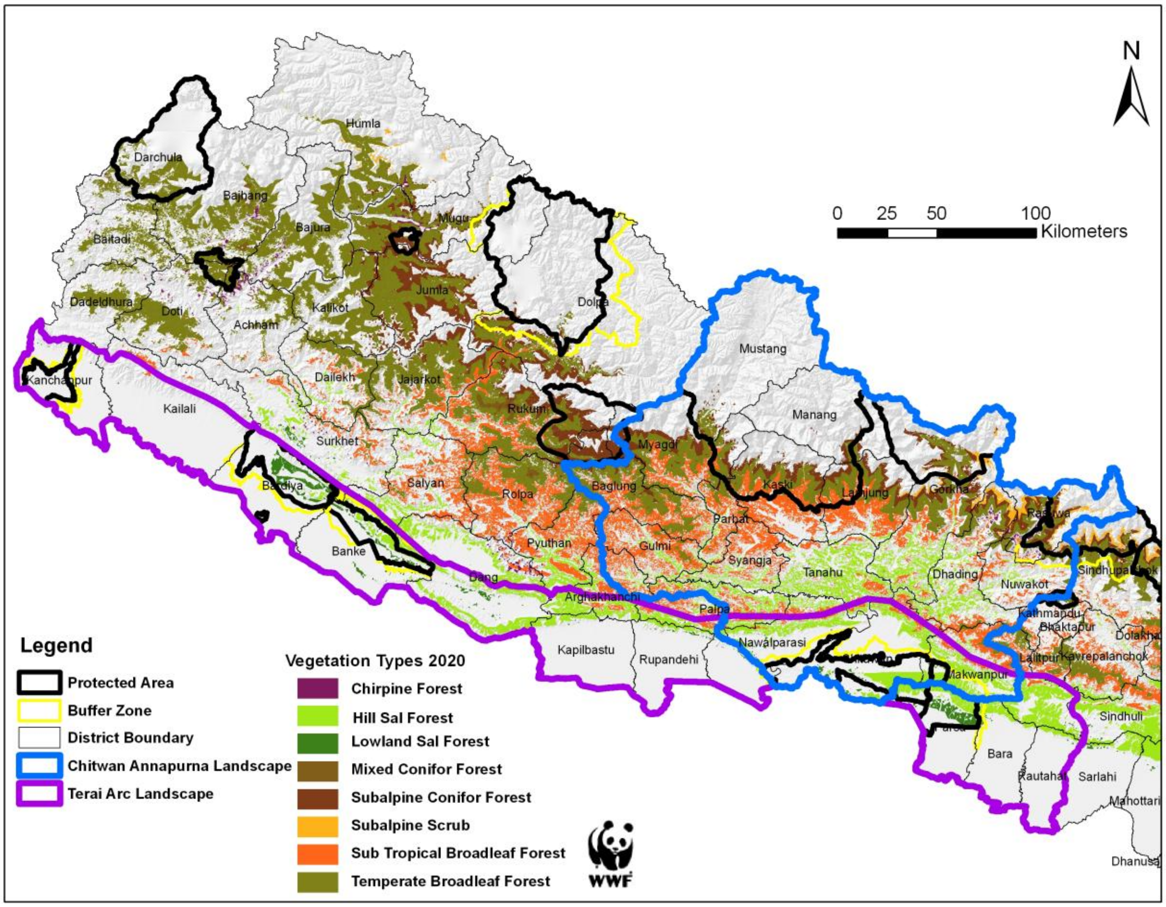


Figure 4. Resilient patches of the vegetation types in 2020 under the A2A climate projection scenario. These patches represent the areas where the vegetation composition is not expected to change under the A2A climate projection, and does not represent forest loss or fragmentation due to non-climate related anthropogenic drivers.

[50] Forest cover map, 2010. Government of Nepal.

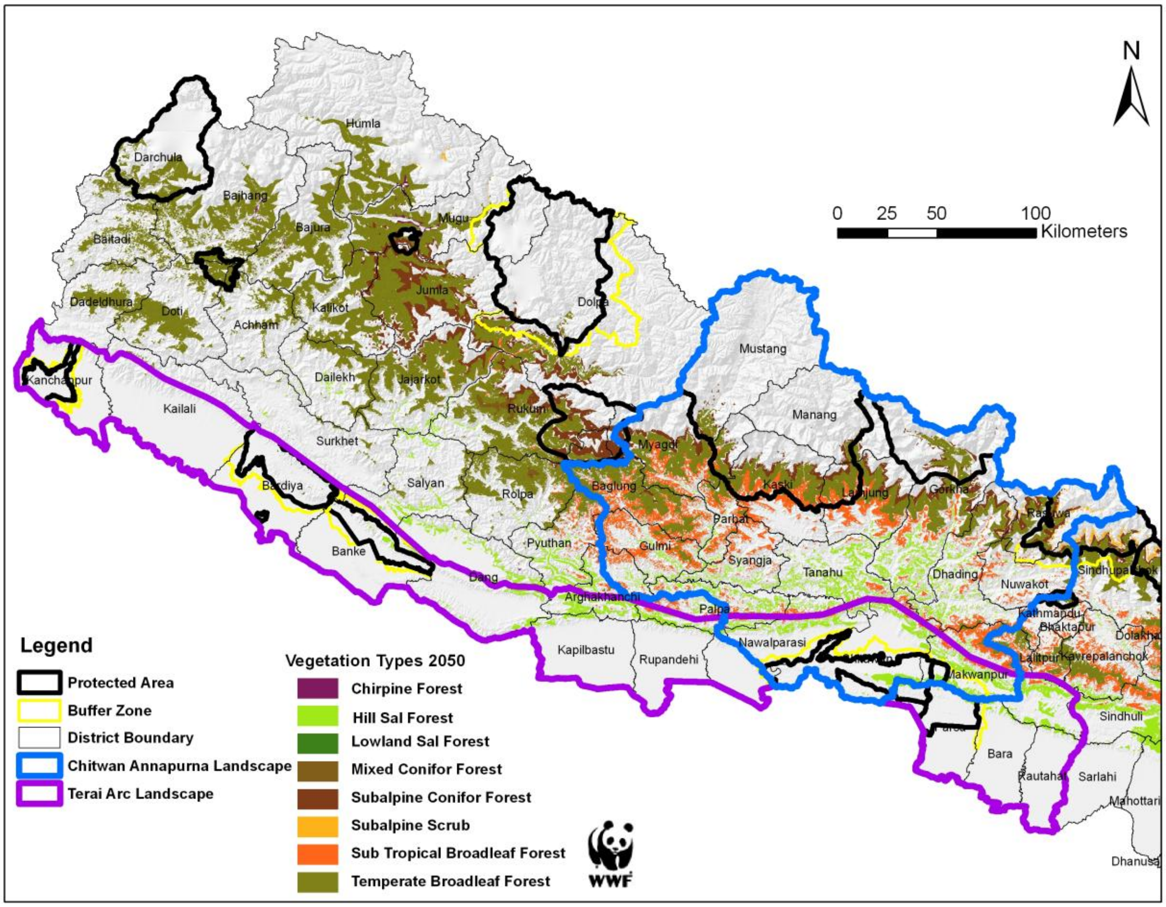


Figure 5. Resilient patches of the vegetation types in 2050 under the A2A climate projection scenario. These patches represent the areas where the vegetation composition is not expected to change under the A2A climate projection, and does not represent forest loss or fragmentation due to non-climate related anthropogenic drivers.

We then overlayed the current protected areas system on the vegetation maps to identify potentially climate resilient areas that are already protected, and also identified the forest patches that are >300 and >500 ha that represent climate macro-refugia[51] in 2020 (Figure 8) and 2050 (Figure 9).

[51] 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, M. B. 2010. Identifying refugia from climate change. 37:1407–1413. doi:10.1111/j.1365-2699.2010.02300.x

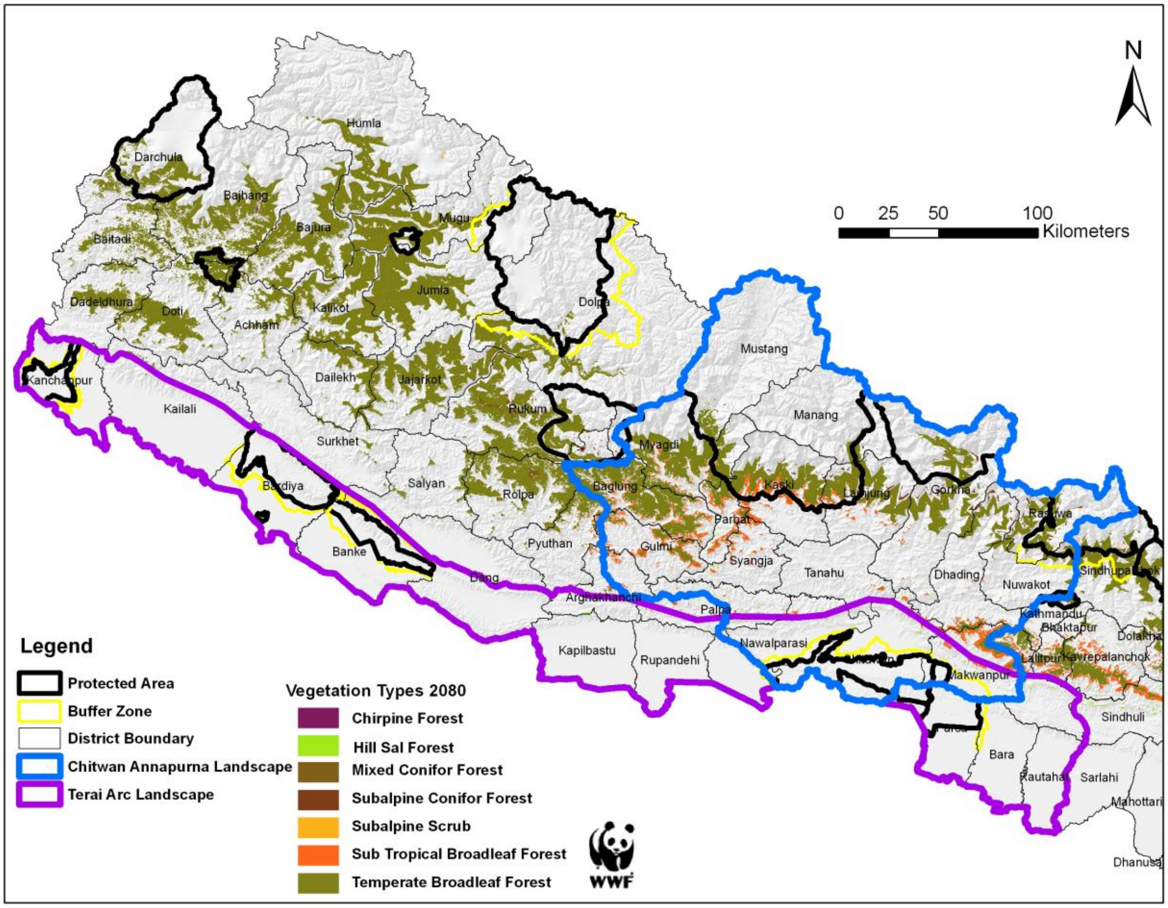
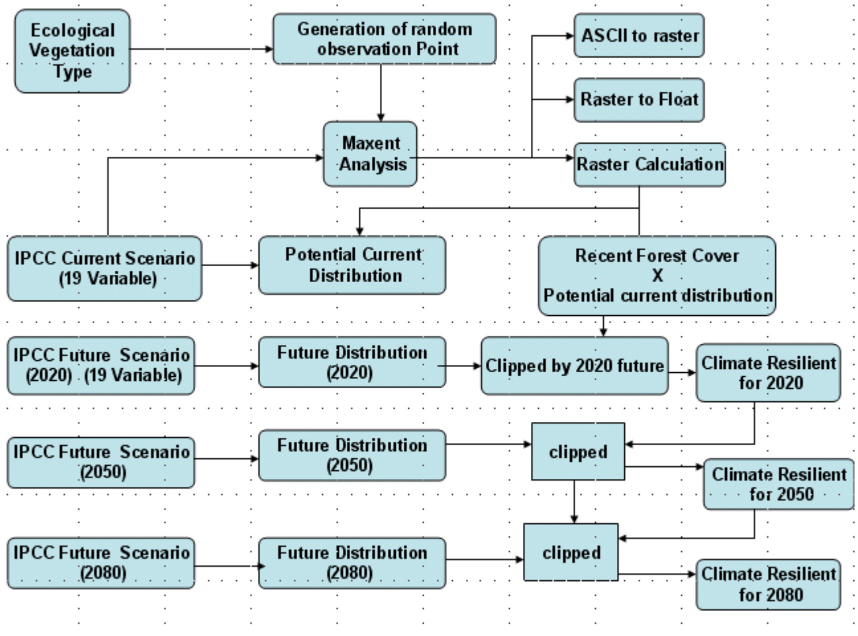


Figure 6. Resilient patches of the vegetation types in 2080 under the A2A climate projection scenario. These patches represent the areas where the vegetation composition is not expected to change under the A2A climate projection, and does not represent forest loss or fragmentation due to non-climate related anthropogenic drivers.

The ‘minor’ habitats for specialist species (e.g., red panda that requires old-growth temperate or mixed conifer forests with bamboo understory) can be identified within these patches of broader resilient types, but not through climate models. The Terai grasslands and savannas were not included as a major vegetation type. Instead, the lowland areas identified as Lowland Sal forest generally coincide with the Terai savanna and grasslands in Nepal. The grasslands are maintained by annual floods and fires, instead of the longer term climate change related drivers. However, changes to annual flow regimes and floods as well as the frequency and intensity of fires could potentially impact the distribution of grasslands.

Figure 7. Flow chart indicating steps in climate projection analysis



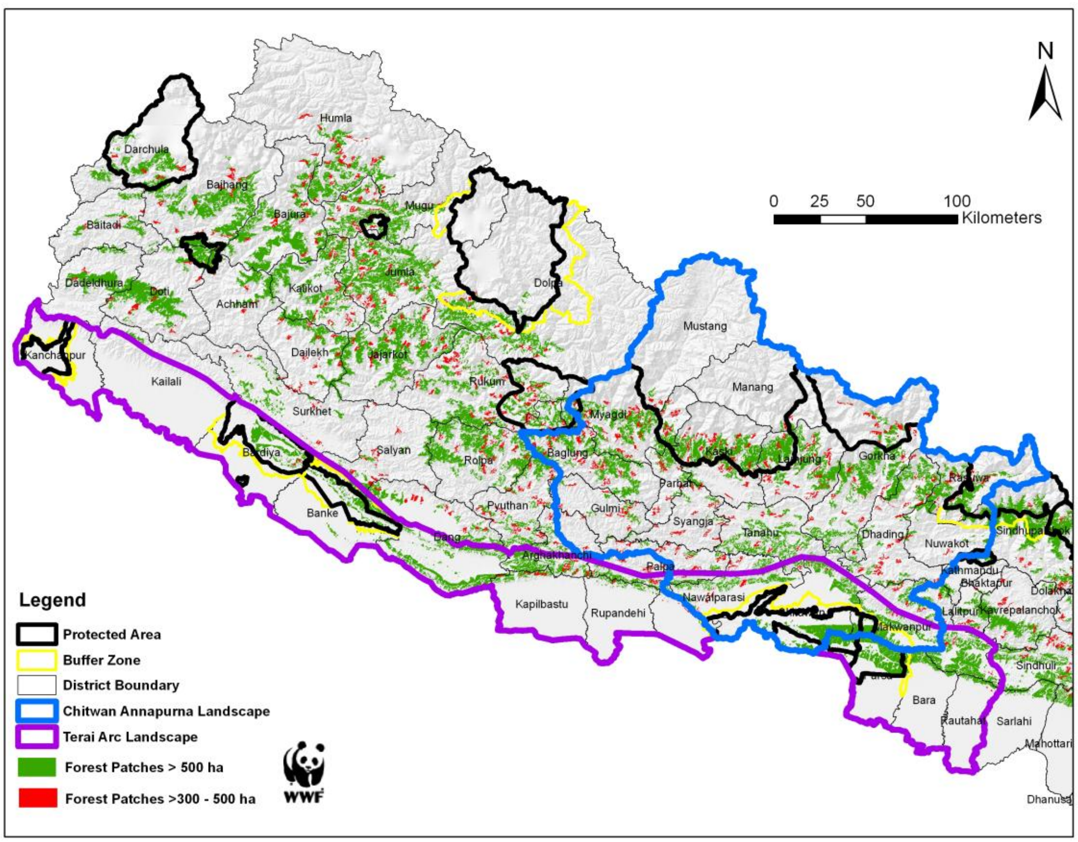


Figure 8. Distribution of larger patches of resilient forests in 2020. These represent potential climate 'macrorefugia' (sensu Ashcroft 2010).

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, extensions 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 may not be as likely to persist. We expect that 'resilient patches' remain so because their 'climate envelope' will remain within the range of tolerance of the community of existing species. This is not to say that climate will not shift at all here at a future time or under a different trajectory, which may be followed by community shifts as well.

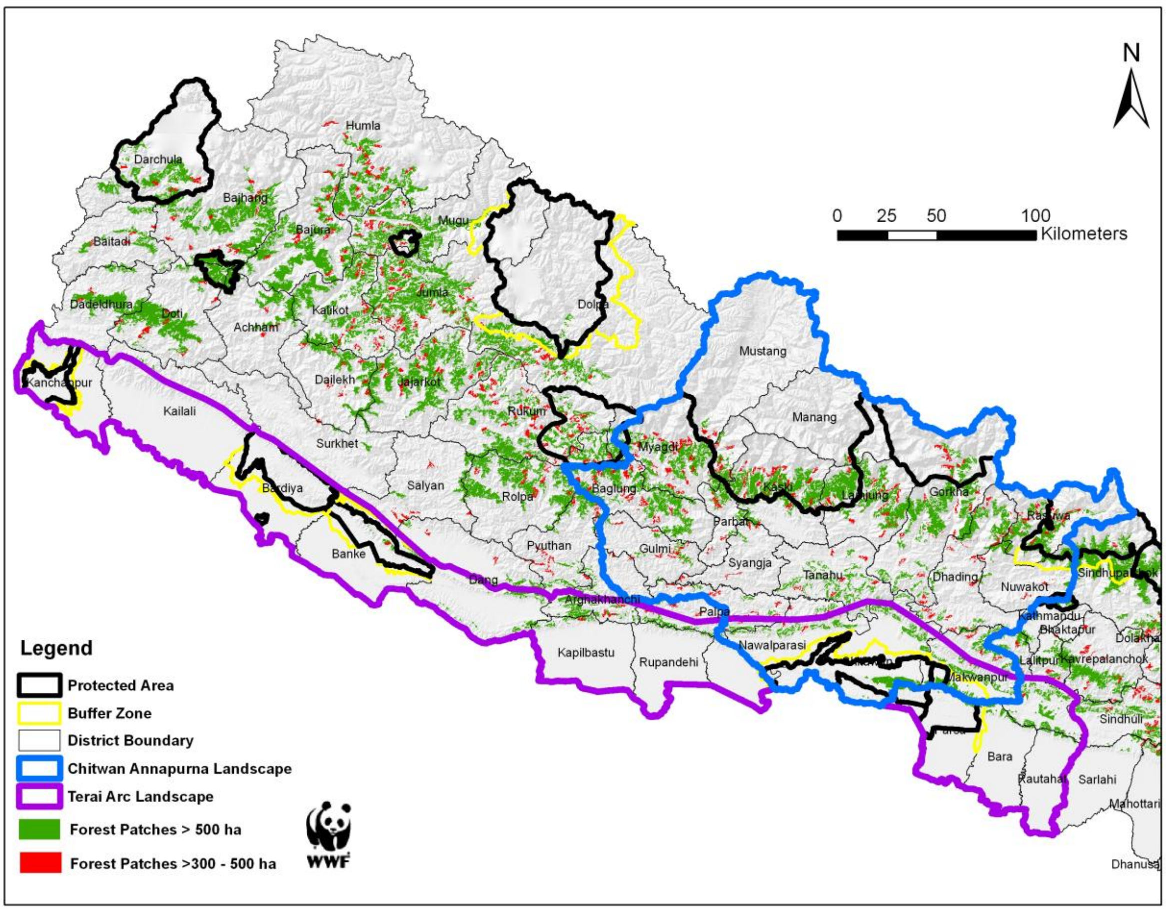


Figure 9. Distribution of larger patches of resilient forests in 2050. These represent potential climate 'macrorefugia' (sensu Ashcroft 2010).

RESULTS

The climate projections indicate that most of the lower and mid-hill forests are vulnerable to climate change under the A2A GHG scenario. These include the Lowland Sal, Hill Sal, Subtropical Broadleaf forests, and the Chir Pine forests. By 2020, there will be very small patches of Chir Pine forests left along the northern extent of the TAL, in the northern extent of Bardia District the southern area of Salyan District (Figure 4). In the CHAL, some patches will remain along the river valleys of Gorkha, Dhading, and Rasuwa districts. However, by 2050, these patches of Chir Pine forests will become converted in both landscapes (Figure 5).

Similarly, by 2020, the Lowland Sal forests may become more fragmented, with small, remnant patches in Bardia, Banke, and Parsa districts, with smaller patches in Dang and Chitwan districts. But by 2050 these patches will also be completely converted.

The Hill Sal forests are distributed along the Churia range, and northwards into the CHAL. Hill Sal forests will persist through 2020 in the Churia districts (Bardia, Banke, Dang, Salyan, Kaplibastu, Arghakhanchi, Palpa, Nawalparasi, Chitwan, and Makwanpur) as relatively contiguous patches, and as smaller fragmented patches into Tanahu, Dhading, Syanja, and the lower parts of Gorkha district in the CHAL (Figure 4). By 2050, the patches along the Churia will become converted and fragmented (Figure 5), although some larger patches >500 ha will persist along the Churia in Dang, Kapilbastu, Arghakhanchi, and Palpa districts (Figure 9). In the CHAL small, scattered patches will remain in the southern parts of Gorkha, Tanahu, Dhading, and Syanja districts through 2080 (Figure 6).

The subtropical forests in the CHAL will persist through 2020 in Baglung, Arghakhanchi, Chitwan, Dhading, Gorkha, Kaski, Lamjung, Makwanpur, Myagdi, Parbat, Gulmi, Palpa, Tanahu, Nawalparasi, and Parbat districts (Figure 4). Very small patches will remain in the TAL, in the northern extents of Arghakhanchi and Makwanpur districts that overlap with the CHAL (Figure 4). By 2050, these forests will become fragmented across the landscapes, and will become lost from Chitwan, Tanahu, and Nawalparasi districts. The extent of Subtropical forests in Dhading, Gorkha, Palpa, and Makwanpur will be considerably reduced (Figure 5). By 2080, there will small fragments remaining in Baglung, Kaski, Lamjung, and in northern areas of Makwanpur, Gulmi, and Parbat (Figure 6).

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 8 and 9). Some of these forests in Myagdi, Kaski, and Lamjung are within the Annapurna Conservation Area. Most of the Subalpine shrub forests will, however, become converted.

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 4-6). Several large patches of these vegetation types will remain (Figures 8 and 9), and these 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.[52] 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.[53]

The mid- and lower-hill forests however, are more vulnerable to climate impacts. By 2050 the Subtropical Broadleaf forests will be extensively converted[54] into a vegetation type with a different species community, the Hill Sal forests will become highly fragmented within a matrix of a different vegetation type, and the Lowland Sal forests will be completely converted in the CHAL (Figures 4 and 5).

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 forests, but these in general 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, especially to conserve the Churia watershed (Figures 4 and 5).

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

---

[52] Olson, D.M., E. Dinerstein, E.D. Wikramanayake, N.D. Burgess, G.V.N. Powell, E.C. Underwood, J.A. D'Amico, I. Itoua, H.E. Strand, J.C. Morrison, C.J. Loucks, T.F. Allnutt, T.H. Ricketts, Y. Kura, J.F. Lamoreux, W.W. Wettengel, P. Hedao, and K.R. Kassem. 2001. Terrestrial ecoregions of the world: a new map of life on Earth. BioScience 51:933-938.

[53] Eriksson,M, X. Jianchu, A.B. Shrestha,R.A. Vaidya, S. Nepal, and K. Sandström. 2009. The changing Himalayas – Impact of climate change on water resources and livelihoods in the Greater Himalayas. ICIMOD publ.

[54] Note 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.

species.[55] According to Shrestha and Joshi[56], this area of central Nepal also has some of the highest concentrations of endemic plants, especially between 3000 and 4000 m. 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, fragmenting the snow leopard's habitat. [57] 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 that can threaten these species.[58]

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 5), 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. Even if the current vegetation assemblages of these forests change due to climate-related drivers, if the older canopy trees remain, hornbills should

---

[55] Basnet, K., P. Shrestha, K.A. Shah, and P. Ghimere. 2000. Biodiversity assessment of corridors linking Annapurna Conservation Area and Chitwan National Park-Parsa Wildlife Reserve. In: Chitwan Annapurna Linkage. Biodiversity Assessment and Conservation Planning. WWF Nepal Program.

[56] Shrestha, T.B. and R.M. Joshi. 1996. Rare, endemic and endangered plants of Nepal. WWF Nepal Program, Kathmandu, Nepal

[57] Forrest, J. L. *et al*. 2012. Conservation and climate change : Assessing the vulnerability of snow leopard habitat to treeline shift in the Himalaya. Biological Conservation 150:129–135.

[58] Yonzon, P.B. and M.L. Hunter. 1991. Cheese, Tourists, and Red Pandas in the Nepal Himalayas. Conservation Biology 5:196–202.

be able to nest, breed, and maintain viable populations. 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. The tragopans and pheasants also require intact undergrowth for feeding and refuge, but 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, 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, connected habitat is conserved. While the common leopard, clouded leopard, and wild dog are found in the subtropical mid-hill forests of the CHAL, tiger is now restricted to the TAL.

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

Mammals

Of the 180 species of mammals recorded from Nepal, 59 species are listed in the National Red Data Book of Nepal.[59] The TAL and CHAL support several, including the large, wide-ranging species such as the tiger, Asian elephant, snow leopard, common leopard, sloth bear (*Melursus ursinus*) and black bear. The ecology and behavior of these species require large spatial habitats and landscape approaches for their conservation. 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 large to mid-sized species such as greater one-horned rhinoceros, 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

[59] ICIMOD. 2007. Nepal Biodiversity Resource Book Protected Areas, Ramsar Sites, and World Heritage Sites. Eds: Pradhan, B.B., Mendez, J.M., Sharma. M., Pradhan, P. and Thaku, A.K., ICIMOD, Minnistry of Environment, Science and Technology, Government of Nepal, and UNEP report.

species are already fragmented with extensive loss from anthropogenic forest clearing, especially in the lowland areas of the TAL. Consequently the lowland species are under greater threat; in fact, species such as the pygmy hog (*Porcula salvania*) and hispid hare (*Caprolagus hispidus*) have already been extirpated from the Terai regions 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 macrorefugia for species such as red panda and musk deer, which have very specialized habitat requirements.

In addition to the charismatic large and mid-sized mammals, there are several smaller species that are restricted to specific forest zones.[60] 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.

Birds

Several of Nepal's birds are migratory species, including altitudinal migrants that spend summers in the mountains and fly down to the lowlands and foothills for the winter. The Kali Gandaki valley of the CHAL is an important route for trans-Himalayan migrants as well as for the altitudinal migrants,[61] and loss of habitat in the CHAL can thus prevent these migrations. Therefore, north-south habitat corridors are important to maintain these seasonal movements, and the CHAL supports and sustains these bird migrations.[62]

---

[60] Abe, H. 1971. Small Mammals of Central Nepal. Journal of the Faculty of Agriculture, Hokkaido University 56: 367-423 Hokkaido University Collection of Scholarly and Academic Papers : HUSCAP 1971

[61] Inskipp, C. and T. Inskipp. 1991. A guide to the birds of Nepal. Second edition. London, UK: Christopher Helm.

[62] Basnet, K., P. Shrestha, K. Shah, and P. Ghimere. 2000. Biodiversity assessment of corridors linking Annapurna Conservation Area and Chitwan National Park-Parsa Wildlife Reserve. Chitwan-Annapurna Linkage Biodiversity Assessment and Conservation Planning. WWF report.

Nepal lists 149 bird species as threatened, of which 99 species are considered to be Critically Endangered (CR) or Endangered (E). [63] 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 (fir or cedar-dominated forests), and broadleaf forests with bamboo (Appendix 5). 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.[64] 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 bird species, although more proximate and shorter-term non-climate related anthropogenic drivers are likely to be more severe threats.

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*), Grey-crowned 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*).[65] Climate impact projections suggest that the alpine grasslands could

---

[63] BCN and DNPWC. 2011. The State of Nepal's Birds 2010. Bird Conservation Nepal and Department of National Parks and Wildlife Conservation, Kathmandu.

[64] Information for habitat specialist birds from BCN and DNPWC. 2011. The State of Nepal's Birds 2010. Bird Conservation Nepal and Department of National Parks and Wildlife Conservation, Kathmandu.

[65] BCN and DNPWC. 2011. The State of Nepal's Birds 2010. Bird Conservation Nepal and Department of National Parks and Wildlife Conservation, Kathmandu.

become encroached by upslope forest migrations.[66] 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 relatively quickly,[67] much before climate-change related impacts on distribution and migration of vegetation types. Grassland management processes include plowing, annual cutting and burning for maximizing mammal species conservation in protected areas with no consideration of the habitat requirements of birds.[68] However, natural disasters 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*).[69]

Several forest dependent birds are likely to be affected by climate change (Appendix 5). 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 refugia due to changes in forest vegetation or structure. Other migratory birds that spend summers further south, but winters in the mid and low hills of the Himalayas may lose nesting habitats.

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 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.[70,71] Other insectivorous riverine species such as forktails, dippers,

---

[66] Forrest, J. L. et al. 2012. Conservation and climate change : Assessing the vulnerability of snow leopard habitat to treeline shift in the Himalaya. Biological Conservation 150:129–135.

[67] Peet, N., A.R.Watkinson, D.J. Bell and B.J. Kattel. 1999. Plant diversity in the threatened sub-tropical grasslands of Nepal. Biological Conservation 88:193–206.

[68] Baral, H.S. 2001. Community structure and habitat associations of lowland grassland birds in Nepal. PhD thesis, University of Amsterdam, Amsterdam, The Netherlands. Unpublished.

[69] BCN and DNPWC. 2011. The State of Nepal's Birds 2010. Bird Conservation Nepal and Department of National Parks and Wildlife Conservation, Kathmandu.

[70] Baral, H. S. 2002. Impact of climate change on Nepal's birds. Danphe 11:6.

wagtails and river redstarts could face changes in prey abundance if river flows become unsuitable for aquatic invertebrates.[72]

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 within Chitwan National Park, Koshi Tappu Wildlife Reserve, and in Lumbini, Ghodaghodi Lake area, Jagdishpur Reservoir, and the Koshi Barrage. While changes in precipitation and subsequent river flows associated climate change can affect these wetland habitats, those 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 as climate refugia, and patches of forests that will remain as micro-refugia in the more climate vulnerable forests of the mid- and lower hills for these habitat specialist bird species. Planning should include maintaining the habitats for breeding and maintaining connectivity for altitudinal migrations, again through smaller-scale planning to identifying the smaller patches of forests that could be resilient to climate change. However, the more immediate threats to habitat conversion and degradation should also be addressed. Monitoring the bird populations, especially during the migratory season, and habitat use will be an essential requirement.

Reptiles and Amphibians

Reptiles and amphibians are poorly studied in Nepal. However the limited information available indicates that there are a few 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.[73]

---

[71] Ghimire, B.C. and J. Thakuri. 2010. Assessment of Ibisbill for the adaptation of climate change in central Nepal. Preliminary report submitted to National Adaptation of Action Project, Ministry of environment, Nepal. Cited in BCN and DNPWC 2011.

[72] Baral, H.S. 2002. Impact of climate change on Nepal's birds. Danphe 11:6.
[73] Nanhoe, L.M.R. and P.E. Ouboter. 1987. The distribution of reptiles and amphibians in the Annapurna-Dhaulagiri Region (Nepal). Zoolgische Verhandelingen. Leiden 240: 1-105

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 6). Frogs in particular are sensitive to habitat degradation, and can be used as indicators of habitat change due to climate change.

Butterflies

Butterflies can be sensitive to impacts of climate change.[74,75] Some butterfly species require specific host plants for food, either during the adult or caterpillar stage, and changes to the vegetation composition can affect these species. Surveys in central Nepal[76] and in some Terai and Churia districts (Dangdeukhuri, Banke, Bardia, Surkhet)[77] have identified several rare and uncommon butterflies that are restricted to specific forest zones, and to specific forest types within these zones (Appendix 7).

Overall, the lowland Terai zone (<1,000 m) and the broadleaf-conifer zone (3,000-3,500 m) had the highest numbers of rare butterflies (Appendix 7). Khanal *et al*. (2012)[78] have identified several 'forest types' or floral associations defined by dominant tree species within each altitudinally defined vegetation zone (Appendix 7) and assemblages of rare butterflies are associated with each forest type. For instance, there are 6 forest types within the mixed broadleaf-conifer zone between 3,000 and 3,500 m (Appendix 7). 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, and 16 species were recorded from the *Rhus succidenia, Taxus baccata, Leucana leucocephala, Quercus semicarpifolia* forest type, which had 8 rare butterfly species.

The tropical zone with Lowland Sal forests including the Terai grasslands, the Subtropical Broadleaf forest zone, and the Temperate Broadleaf forest zone had a relatively high number of rare species (Appendix 7). There is also little or no overlap in the distribution of these species

---

[74] Cormonta, A., R. Jochema, A. Malinowskaa, J. Verbooma, M.F. WallisDeVriesc, and P. Opdama. 2012. Can phenological shifts compensate for adverse effects of climate change on butterfly metapopulation viability? Ecological Modelling. 227:72–81

[75] Thomas, C. D., A.M. Franco, and J.K. Hill. 2006. Range retractions and extinction in the face of climate warming. Trends in Ecology & Evolution 21:415–6.

[76] B. Khanal, M.K. Chalise and G.S. Solanki. 2012. Diversity of butterflies with respect to altitudinal rise at various pockets of the Langtang National Park, central Nepal . International Multidisciplinary Research Journal 2:41-48

[77] Khanal. B. 2008. Diversity and status of butterflies in lowland districts of west Nepal. J Nat Hist Mus. 23:92-97

[78] B. Khanal, M. K. Chalise and G.S. Solanki. 2012. Diversity of butterflies with respect to altitudinal rise at various pockets of the Langtang National Park, central Nepal . International Multidisciplinary Research Journal 2:41-48

across forest types, possibly reflecting host plant specificity. Because climate projections indicate that the forests in the tropical (Lowland Sal) and subtropical zones (Hill Sal forests, Subtropical Broadleaf forests) are vulnerable to change, resilient patches should be conserved if these rare butterfly species are to be conserved, 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.

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 (Figure 10).[79] Shrestha and Joshi[80] have listed 47 species of threatened plant species and 88 species that are endemic to Nepal from the CHAL region (Appendices 8 and 9). The forests in these areas are already fragmented, and the climate projections indicate that the remaining Subtropical Broadleaf and

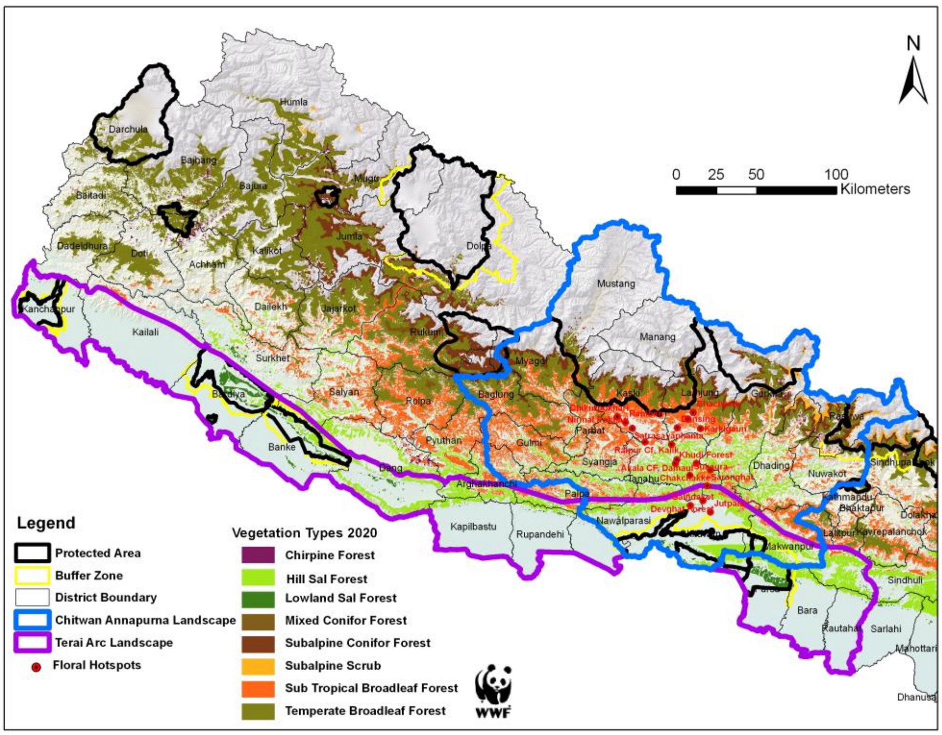


Figure 10. Floral 'hotspots' in the CHAL. (Basnet et al 2000).

---

[79] Basnet, K., P. Shrestha, K. Shah, and P. Ghimere. 2000. Biodiversoty assessment of corridors linking Annapurna Conservation Area and Chitwan National Park-Parsa Wildlife Reserve. Chitwan-Annapurna Linkage Biodiversity Assessment and Conservation Planning. WWF report.

[80] Shrestha, T.B. and R.M. Joshi. 1996. Rare, endemic and endangered plants of Nepal. WWF Nepal Program, Kathmandu, Nepal

Sal forest areas will become extensively converted by 2050. However, because of the uncertainties associated with climate projections any areas that will remain resilient by 2020 should be prioritized for conservation and monitored for change.

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 the most conservative projections. Targeting these patches, especially the larger patches, for conservation in a landscape conservation plan will be a 'no regrets' strategy.
- Maintain ecological connectivity by maintaining habitat corridors and linkages. Strategically restore corridors and linkages where necessary.
- Conduct a land facets analysis[81] that uses landscape units defined by topographic, soil, and insolation variables to identify climate micro-refugia and connectivity in the context of climate change, especially in the vulnerable forest ecoregions.
- Run the analysis using other GHG scenarios and consider those outputs in the planning process as well.
- Grassland management should also consider the habitat requirements of species other than charismatic mammals, especially the grassland birds.
- Landscape planning should include maintaining connectivity for altitudinal migrations.
- Consider 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.

[81] Brost, B. and P Beir. 2012. Use of land facets to design linkages for climate change. Ecological Applications 22:87–103

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

Table also shows the relationships between the TISC and Stainton and LRMP classifications.

LRMP 1986[82]	Stainton 1972[83]	TISC, 2000[84]	This analysis
Sal	Sal Hill Sal	Lower Tropical Sal and Mixed Hardwood Forest Hill Sal	Lowland Sal forest Hill Sal
Acacia-Dalbergia	*Dalbergia-Acacia*	Sal Zone Riverine Habitat	Lowland Sal
Tropical Mixed Hardwood	*Terminalia* Tropical Deciduous Riverine Forest	Hill Sal Upper Tropical Riverine Forest	Hill Sal Hill Sal
	Tropical Evergreen Forest Sub-tropical Evergreen Forest Sub-tropical Deciduous Hill Forest *Schima-Castanopsis*	Hill Sal *Eugenia-Ostodes* Forest Hill Sal Forest *Schima-Castanopsis*	Hill Sal Subtropical Forest Hill Sal Subtropical Forest
	Alnus Forest	*Schima-Castanopsis*	Subtropical Forest
   Quercus spp.	Sub-tropical Semi-evergreen Hill Forest *Castanopsis tribuloides-C. hystrix* Forest *Q incana-*	Schima-Castanopsis *Schima-Castanopsis* Lower temperate Oak	Subtropical Forest Subtropical Forest Temperate Broadleaf forest

[82] Kenting Earth Science Limited (1986). Land Resource Mapping Project: Land utilization report appendices two and three. Kenting Earth Science Limited, Canada
[83] Stainton, JDA (1972): Forests of Nepal. John Murray, London.
[84] 2002, Forest and Vegetation Types of Nepal. TISC Document Series No. 105. Dept of Forest, HMG/NARMSAP, International Year of Mountain Publication, Nepal.

	Q.lanuginosa		
Chir Pine	*Q dilata* *Pinus roxburghiii*	Lower Temperate Oak Chir Pine	Temperate Broadleaf forest Chir Pine Forest
		Chir Pine broadleaved	Subtropical Forest
	Upper Temperate Mixed broadleaved Lower temperate mixed broadleaved	Deciduous Maple-Magnolia-Sorbus; mixed Rhododendron-Maple Mixed oak-Laurel	Temperate Broadleaf forest 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 Mixed Blue Pine-Oak	Subalpine conifer Mixed conifer
	Abies pindrow	West Himalayan Fir-Hemlock-Oak Fir-Blue pine	Mixed conifer
	Picea smithana	Spruce	Subalpine conifer
	Cupressus Rhododendron Forest *Cedrus*	Cypress Rhododendron forest Cedar	Subalpine conifer Sub alpine shrub forest Subalpine conifer

Appendix 2. Heuristic estimates of relative contributions of the environmental variables to the Maxent model under the 2020 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 3. 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 4. 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 5: Some bird species vulnerable to climate change based on potential impacts on habitats.[85]

- Oriental Hobby (*Falco severus*). Nationally threatened status: CR. Habitat: wooded hills in the tropical and subtropical zone, up to 1525m. 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 250m. 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 250-365m. 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 250-1000m. Fragmentation of subtropical and lowland sal forests could be potential climate-related threats.

[85] 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.

- 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 245m.
- 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 455m, 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 1000-1700m.
- 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 2195-2300m.

- 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 300-1220m. 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 275m
- 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 1200-2300m.
- 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 275m.
- Long-tailed Sibia (*Heterophasia picaoides*). Nationally threatened status: CR. Very rare and local probable resident. Habitat: broadleaved forest in tropical and subtropical zones from 305-900m.
- 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 365m.
- 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 6. Some habitat specialist reptiles and amphibians from the CHAL region.

(From Nanhoe and Ouboter,1987).[86]

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 between 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. >3500m

Reptilia

---

[86] Nanhoe, L.M.R. and P.E. Ouboter. 1987. The distribution of reptiles and amphibians in the Annapurna-Dhaulagiri Region (Nepal). Zoolgische Verhandelingen. Leiden 240: 1-105

- *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 7. Rare and Uncommon butterfly species that could be vulnerable to climate change.

Rare butterfly species of forest zones of Central Nepal[87]

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)

[87] B. Khanal, M. K. Chalise and G.S. Solanki. 2012. Diversity of butterflies with respect to altitudinal rise at various pockets of the Langtang National Park, central Nepal. International Multidisciplinary Research Journal 2012, 2(2):41-48.

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[88]

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*
- *Chliaria othona*
- *Zizeena otis otis*

---

[88] Khanal. B. 2008. Diversity and status of butterflies in lowland districts of west Nepal. J Nat Hist Mus. 23:92-97

- *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 jangala* (rare)

NYMPHALIDAE

- *Cyrestis thyodamus*
- *Kallima inachus*

SATYRIDAE

- *Ypthima baldus baldus*
- *Ypthima singala*
- *Ypthima huebneri*
- *Elymnias hypermnestra*

DANAIDAE

- *Tirmala septentrionis*

HESPERIIDAE

- *Thoressa aina* (rare)
- *Badamia exclamationis*

Appendix 8. Endemic plants from CHAL and TAL.

(Data from Shrestha and Joshi.)

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
	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
	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 9. 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
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