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Selecting tree species for climate change integrated forest restoration and management in the Chitwan-Annapurna Landscape, Nepal

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Abstract

Climate change will affect forest vegetation communities, and field surveys have already indicated measurable distribution range shifts in some tree species. As forests play an important role in stabilizing steep slopes and provide vital ecological goods and services, the Government of Nepal has been encouraging forest restoration and sustainable management. However, reforestation and afforestation programs should consider the long term survivorship of the trees selected for reforestation to build climate adaptation and resilience. Thus, the choice of species should include species that would be expected to grow within the elevation zone or in the particular habitat under future climate change scenarios. In this analysis, we have assessed the response of 12 important tree species to climate change using the IPCC A2A GHG scenario with GCM-based climate envelopes to provide guidelines and recommendations for climate change-integrated forest restoration and management in the Chitwan-Annapurna Landscape (CHAL). The results indicate that several species could exhibit range shifts due to climate change, with an overall trend for species in the lower elevations to move northwards or further up the slopes within the current area of distributions. Analyses such as this, though not perfect, can help to make critical and informed decisions to support long-term forest restoration programs.

Key Words: *Climate Change, forest ecosystem, vegetation shifting, landscape conservation*

Introduction

Global climate change is now considered to be an important driver of ecological change, including causing range shifts or even local extinctions if species cannot adapt to or move from unfavorable environmental conditions (Parmesan, 2006). The responses to warming climates are expected to be pole ward or upslope movements, but the shifts will also be influenced by various local abiotic and biotic conditions, such as local land use and dispersal or movement barriers, micro-climates, the use of plants and animals by people, interspecific interactions, species-specific eco-physiological tolerances to environmental conditions, vagility, nutrient availability, edaphic conditions, etc. (Parmesan and Yohe, 2003; Parmesan et al., 2011; Schickhoff et al., 2015).

Studies in the Himalaya, including in Nepal, already show measurable responses among some tree species, manifested as northward and upslope shifts (Dubey et al., 2003; Shrestha and Devkota, 2010; Vijayprakash and Ansari, 2009). A climate change projection modelled for eight major vegetation types in the Nepal Himalaya also suggests that some forest communities are vulnerable to climate change, but some may be more resilient and will remain unchanged under projected climate scenarios (Jung Thapa et al., 2016). However, the study also shows that the complex topography of the Himalayan mountains can create resilient climate micro-refugia even within the larger spaces of climate vulnerable areas (Jung Thapa et al., 2016).

Many people in Nepal still depend heavily on forest-based resources, including several tree species, for a variety of uses ranging from timber to food, fodder, medicines, wood for utensils and crafts, and fertilizer (Chaudhary, 2000). But decades of unsustainable harvesting have caused many of Nepal's natural forests to become highly degraded, threatening the biodiversity of these ecosystems as well as sustainability of ecosystem goods and services that support livelihoods and wellbeing (Chaudhary, 2000). Degraded forests are also less resilient to climate change (Noss, 2001). Because climate change is expected to result in more frequent and more severe weather extremes and increased natural disasters, forest restoration is also important to mitigate slope destabilization and consequent natural disasters. Loss of forest resources and vulnerability to such disasters will disproportionately affect the poor who are marginalized to less productive and unsafe areas, and women who usually seek and collect forest resources, and are thus more exposed to natural disaster risks (Neumayer and Plümper, 2007; Vakis, 2006).

In this study, we modelled the responses to climate change by several key tree species (Table 1) that are dominant components of the forest vegetation and projected their potential future distributions in the Chitwan Annapurna Landscape (CHAL), based on an

IPCC A2A greenhouse gas (GHG) climate projection to provide an initial methodological approach to assist with tree species selection for climate suitable planting (Duveneck and Scheller, 2015) in forest management.

Study area

The Chitwan-Annapurna Landscape (CHAL) is a river basin conservation landscape extending from Chitwan National park in the South to Annapurna Conservation area in the North. The landscape is drained by eight major rivers (Kali Gandaki, Seti, Madi, Marsyangdi, Daraundi, Budi Gandaki, Trishuli, Rapti) and their tributaries of the broader Gandaki River system. The total area of the landscape is 32,090 sq km and the geographical extension ranges from 82°52'51"to 85°48'10" E Longitude to 27°21'20" to 29°19'50" N Latitude. CHAL itself is bounded by the Gandaki river basin. It exhibits much scenic beauty, ranging from the rain shadow of the trans-Himalayan area and the snowcapped mountains of Annapurna, Manaslu and Langtang in the north, descending southwards through diverse topography to the mid-hills, Churia range and the flat lowlands of the Terai. It contains seven major sub-river basins: Trishuli, Marsyandi, Seti, Kali Gandaki, Budi Gandaki, Rapti and Narayani. The landscape has high biodiversity value and is rich in natural and cultural heritage. The Kaligandaki river gorge, its river valley and most of the section is an important transit route for migratory birds and is home to endangered species like snow leopard, and red panda. The 12 permanent climate change monitoring plots have been established by USAID Hariyo Ban for long term research. CHAL has a human population of over 4 million, many of whom live in very isolated topography with poor access to market centres. They are more dependent on forest resources and ecosystem services for their livelihoods. Diverse tourism i.e.,

Table 1. Tree species used in the climate projection.

High Himal
Juniper (spp.)
High Mountains
Blue pine (*Pinus wallichiana*), Fir (*Abies* spp.), Birch (*Betula* spp.), Rhododendron, Juniper (*Juniperus* spp.), Oak (*Quercus* spp.), Spruce, Alder (*Alnus nepalensis*)
Middle Mountains
Katus (*Castanopsis* spp), Chir pine (*Pinus roxburghii*), *Tejpat* (*Cinamomum tamala*), *Champ* (*Michelia champaka*); Oak (*Quercus* spp.), *Chilaune* (*Schima wallichi*), Alder (*Alnus nepalensis*)
Churia/Siwaliks
Chir pine (*Pinus roxburghii*), *Tejpat* (*Cinamomum tamala*), *Amala* (*Emblica officianalis*), *Sal* (*Shorea robusta*), *Champ* (*Michelia champaka*)

nature based, wildlife based tracking, cultural and religions based are major economic activities in this region.

The dominant tree species chosen were associated with forests of the High Mountain, Middle Mountain, Churia (Siwalik) and Terai physiographic zones of Nepal (Table 1) to assess their future distribution based on the emission scenario reported in the special report on Emission scenario (SRES) by the Intergovernmental Panel on Climate Change (IPCC) (www.grida.no.climate/ipcc/emission) for the year 2020, 2050 and 2028 obtained via the worlsclime homepage. The species selected have NTFP and timber values for local communities. We chose the A2A GHG scenario-the highest IPCC GHG emission scenario-because recent assessments indicate that GHG emissions during the 2000's exceeded the highest predictions by the IPCC (IPCC, 2007; Raupach et al., 2007; Hansen, Sato and Ruedy, 2012; Shrestha, Gautam and Bawa, 2012; World Bank, 2012).

Table 2 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

We used the DoF (2002) map to select 1000 occurrence points of each forest vegetation type and train the model to project the distributions of some key representative species in them under future climate conditions in the CHAL. This DoF (2002) map of forest classes (Figure 1) represents an extrapolation of forests before anthropogenic conversion and degradation and was created by experts based on their knowledge and assumptions. While these extrapolations have some inherent biases, we used it to avoid the greater biases in current forest cover maps due to extensive anthropogenic forest conversion.

We generated >1,000 random observation points for the respective forest classes assigned to the individual species, and used them in Maxent (Phillipps, Anderson and Shapire, 2006) along with 19 WorldClim bioclimatic variables (Table 2). The bioclimatic variables are biologically meaningful variables and have been used to map climate influenced distributions of several species using GCM models worldwide.

The future distributions of the species represent equilibrium climate for 2050 under the A2A GHG emission scenario, which was projected with a downscaled HADCM3

General Circulation Model (GCM) (Ramirez-Villegas and Jarvis, 2010). The HADCM3 GCM (Mitchell *et al.,* 2004) was selected because it is a moderate GCM at a global scale and appears to replicate historical climate in Nepal fairly well (Forrest *et al.,* 2012).

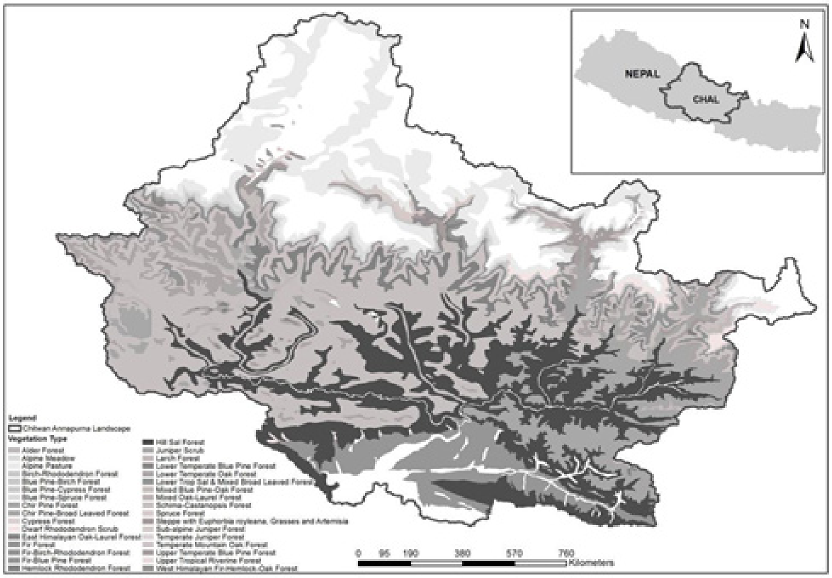

Figure 1: Vegetation types of CHAL (DoF, 2002)

Results and Discussion

Climate envelope models for selected tree species

Juniper, *Juniperus spp*. The A2A GHG model indicates that Juniper will shift upslope from the current distribution (Dubey et al., 2003; Shrestha and Devkota, 2010; Vijayprakash and Ansari, 2009). Because of its ability to colonize and grow on barren lands, Juniper is used to reforest high elevation areas of the Himalaya (Rawat and Everson, 2002).

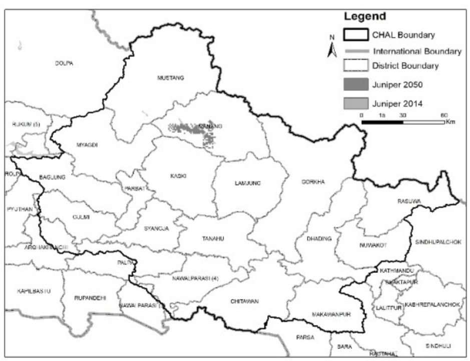

Figure 2: Projected distribution of Juniper in 2050 under the IPCC A2A GHG

East Himalayan Fir (*Abies spectabilis*). Fir occurs as a dominant canopy tree species, but is also mixed with broadleaf forests, especially with Rhododendron, Birch (*Betula*), and Oak (*Quercus spp*.). Therefore, for this analysis, we assigned Fir to several mixed forest types, including Fir-Birch-Rhododendron Forest and Fir-Oak-Rhododendron Forest from 2400 to 4400 m where Fir inclusive forests are distributed as a narrow, undulating band in the ecotone of the High Mountain and High Himal zones. The model predicts that Fir will have a wider distribution, extending the range both northwards into the High Himal within the High Mountain zone from its current distribution (Figure 3). Studies from Langtang National Park already shows an upward shift in the distribution of Fir, attributed to warming winter temperatures (Gaire *et al*., 2011), with high recruitment of saplings and younger age stands in the higher altitude edges of the range (Narayan *et al.,* 2011). Fir is sought after for construction, and can be used to reforest degraded slopes with sustainable extractive management.

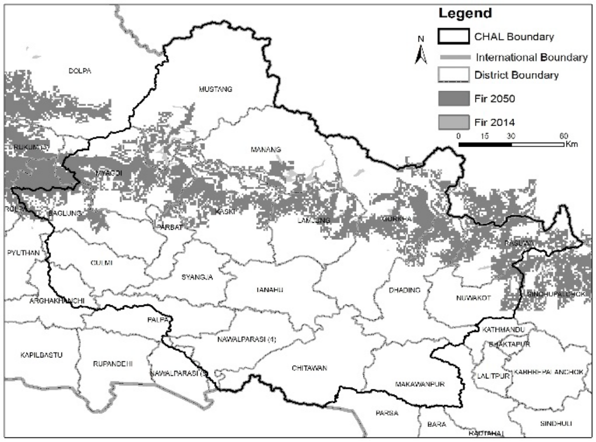

Figure 3: Projected distribution of Fir in 2050 under the IPCC A2A GHG scenario.

Himalayan birch, *Betul autilis*. Birch was associated with the Birch-Rhododendron and Fir-Birch-Rhododendron forests. In the CHAL, the Birch-Rhododendron Forest occurs as a narrow band in the upper regions of the High Mountain zone, in Kaski, Manang, Lamjung, Gorkha and Rasuwa districts (Figure 4). The model predicts that the range distribution of Birch will extend further uphill along the catchment slopes, but not significantly in latitudinally. Since Birch is a fast-growing species it can be used to reforest and stabilize degraded catchment slopes in areas surrounding the current distribution area, especially in areas that are expected to become moister from pre-monsoon precipitation (Liang et al., 2014).

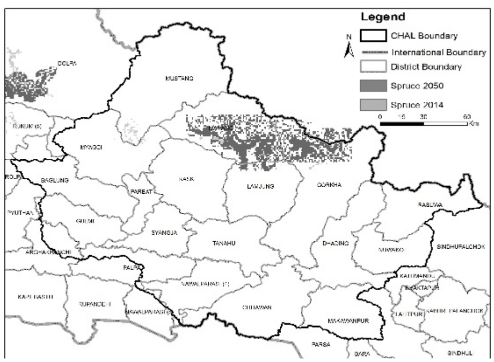

Figure 4: Projected distribution of Spruce in 2050 under the IPCC A2A GHG scenario.

Spruce, *Picea smithiana*. Spruce grows between 2200 and 3300 m in areas that are partially sheltered from the direct impacts of the monsoon. In the CHAL, spruce forests are restricted to small areas of Manang and northern Gorkha districts, where they ascend along the dry valleys of the High Himal zone. The model indicates a local expansion of spruce within these two districts (Figure 4).

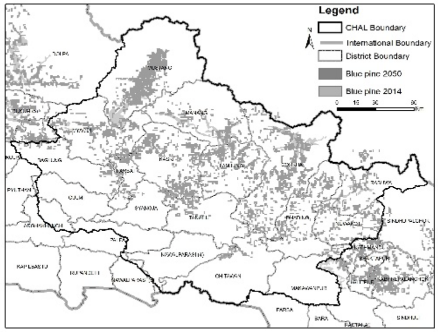

Figure 5: Projected distribution of Blue pine in 2050 under the IPCC A2A GHG scenario.

Blue pine, *Pinus wallichiana*. Blue pine usually grows between 1800 and 3600 m, and occasionally ascends to elevations of 4400 m. In the CHAL, Blue pine is found in Myagdi, Rasuwa, lower parts of Mustang and Manang, and the northern areas of Gorkha districts (Figure 5). The model predicts that the range of Blue pine could extend further northwards into the High Himal zone along the Gandaki river valley in Mustang, and further south along the Gandaki river valley Blue pine is relatively cold tolerant, and can be used for afforestation in the high elevation areas, especially in areas that are less moist.

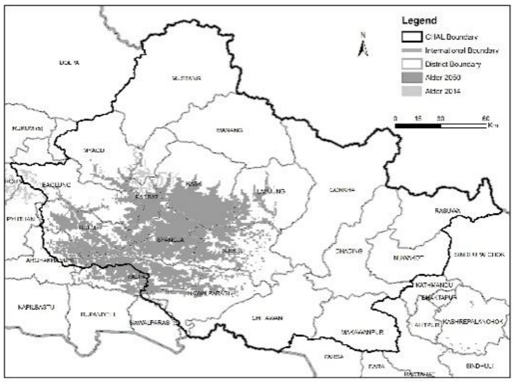

Figure 6: Projected distribution of Alder in 2050 under the IPCC A2A GHG scenario.

Himalayan Alder, *Alnus nepalensis*. This is a pioneer species that readily colonizes landslide-affected areas, degraded forests, abandoned agricultural areas, and areas otherwise disturbed, but also occurs naturally as pure stands or in mixed forests (Sharma, Sharma and Pradhan, 1998). Alder has a wide elevation range distribution, growing from 500 to 3000 m in Nepal. In the CHAL, Alder forests are found as narrow bands along the rivers and ravines in the Middle and High Mountain zones (Figure 6). The model indicates that the range distribution of Alder could extend further away from the riverine areas. Because Alder is a fast-growing pioneer species, it could be used to reforest degraded slopes, to rapidly stabilize degraded slopes and then gradually phase them into mixed stands.

Chilaune, Schima wallichii. The Schima-dominated forests lie below the oak forests, in the subtropical and lower temperate forest zone between 1000-2000 m, especially in wetter south-facing slopes and moister north-facing slopes (Figure 7). The model indicates that *Schima* will extend its range northwards in the High Mountain zone and even partially into the High Himal zone, but will continue to survive in most of its current range. The overall wetter, warmer conditions predicted due to climate change could create growing conditions favourable to this species, which is already widely used in community forestry.

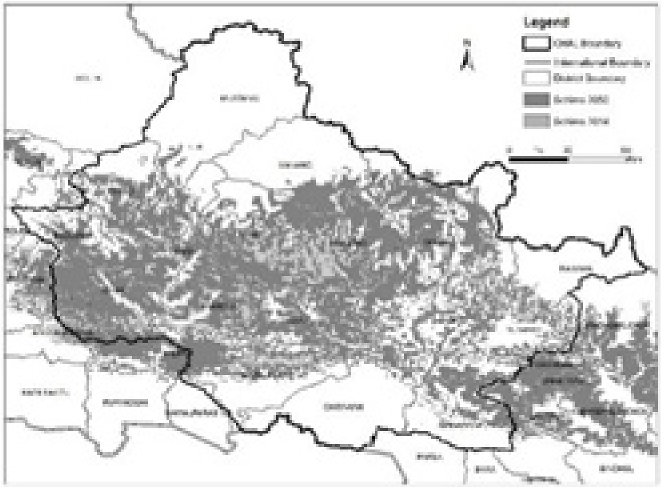

Figure 7: Projected distribution of Schima in 2050 under the IPCC A2A GHG scenario.

Castanopsis spp. There are three species of *Castanopsis* that grow in the Middle Mountain zone: C. hystrix from approximately 1000 to 2500m, *C. indica* from 1200 to 2900, and *C. tribuloides* from 450 to 2300 m. *Castanopsis* was associated with the *Castanopsis-Laurel* and *Schima-Castanopsis* forests. The model predicts the current range of the genus will become patchy, with a slight northward shift (Figure 8). But in particular, *C. tribuloides* has the widest distribution of *Castanopsis* in Nepal, with an elevation range extending from the high elevation Hill Sal forests to

Figure 8: Projected distribution of Castanopsis in 2050 under the IPCC A2A GHG scenario.

temperate forests dominated with laurels and oak. It grows on a variety of soil types and tolerates a wide precipitation regime, indicative of generalist ecophysiological parameters with high climate resilience. C. indica has a narrower elevation range, being confined to the temperate broadleaf forest zone, and is more common in areas with high rainfall. The trees can be used in reforestation programs, especially in the northern regions which could receive more rainfall under climate change scenarios. *C. hystrix* grows in eastern Nepal, in association with *C. tribuloides* and oak (*Q. lamellosa*).

Oak, *Quercus spp*. There are six species of Oak (*Quercus*) that grow in the Middle and High Mountain zones: Q. floribunda from 2100 to 2700 m, *Q. semecarpifolia* from 1700 to 3800 m, *Q. lanata* from 1750 to 2400 m, *Q. leucotrichophora* from 1650 to 2400, *Q. lamellosa* from 1600 to 2800, and *Q. glauca* from 450 to 3100 m. The Oaks were associated with a number of temperate broadleaf and mixed broadleaf forest types, especially the Temperate Mountain Oak Forest and Lower Temperate Oak Forest, and distributed in the Middle and High Mountain zones, with the Lower Temperate Oak Forests extending down to the latter (Figure 9) and the High Mountain oak-dominated forests above, distributed as a narrow, undulating band just below the band of Fir forests. The model indicates that the distribution of oaks will extend both northwards and southwards, including into the High Himal physiographic zone, spreading along the river valleys of the Gandaki River system.

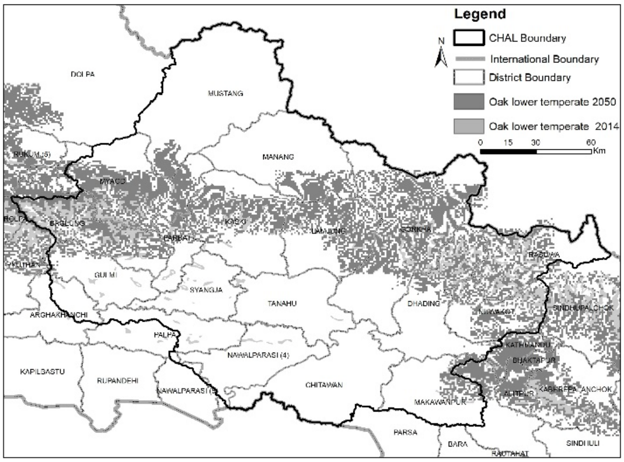

Figure 9: Projected distribution of Upper Temperate Oak in 2050 under the IPCC A2A GHG scenario.

Closer examination of the suite of oak species indicates differences in their habitats, with some species growing better in drier, south-facing slopes and others in moister north-facing slopes. The different elevation ranges also indicate differences in tolerance thresholds for temperature regimes. These ecophysiological differences among species may explain the northward and southward expansion of the oaks indicated in the climate model output.

Climate models for other areas suggest that high elevation oaks such as *Q. semecarpifolia* which currently dominate temperate forests in the mid- to upper elevations, may become isolated in high peaks (Sapkota, Tigabu and Oden, 2009). However, this study indicates that the montane oaks may survive along the lower slopes of catchments, but within the narrow elevation band in the upper temperate region. A study of *Q. floribunda* has shown that the species consists of several populations with different ecophysiological characteristics that adapt the species to survive different environmental conditions of drought and precipitation (Singh, Singh and Skutsch, 2010). Other studies suggest that seed maturity of *Q. floribunda* and *Q. semecarpifolia*, now closely tied to the timing of monsoon rainfall, could become asynchronous, affecting germination and seedling recruitment and survival (Singh, Singh and Skutsch, 2010). Over exploitation of slow growing oaks for fuelwood and fodder can also affect seed production and recruitment; thus, sustainable management will be necessary to enable forest restoration and growth of these forests (Hussain et al., 2008). In the northern districts oaks can be used to reforest degraded or destabilized slopes. However, the choice of species should consider the habitat preferences of the different species, and their ecophysiological adaptive capacities to emerging climatic conditions based on environmental tolerance thresholds and responses to human disturbances.

Chir Pine, *Pinus roxburghii*. Chir Pine usually grows in the sub-tropical belt, on the drier south and southeast-facing slopes. The species cannot usually compete with broad leaved trees in wetter areas, including south-facing slopes, which may explain the absence from the central regions of the CHAL along the wetter Gandaki basin where they are generally found along the peripheral areas, in the eastern and western districts (Figure 10). The current distribution is largely within the Middle Mountain physiographic zone, although mono-stands of Chir Pine Forests extend to the High Mountain zone in the eastern districts, along the river valleys. The model does not indicate a significant change in the range distribution within the CHAL, except in Gulmi and Baglung districts.

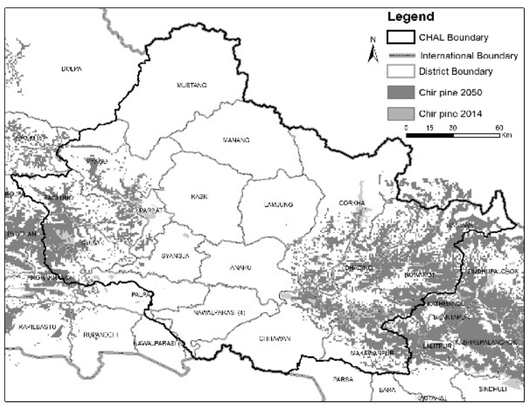

Figure 10: Projected distribution of Chir pine in 2050 under the IPCC A2A GHG scenario.

Chir pine can tolerate poor soil conditions but does not grow well on badly drained soils. The pure stands in drier sites are considered to be climax communities. The absence of an undergrowth is considered to encourage erosion, especially on steep slopes; therefore, forestry projects, especially on steep slopes, should encourage colonization, regeneration, and emergence of other tree and shrub species.

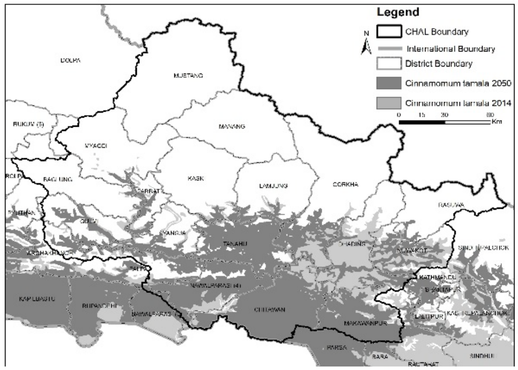

Figure 11: Projected distribution of Cinnamomum tamala pine in 2050 under the IPCC A2A GHG scenario.

Tejpat, *Cinnamomum tamala*. Tejpat is relatively common and widespread in the subtropical and lower temperate forests of the lower Middle Mountains, Churia and the Terai, between 500 and 2200 m. It is associated with several forest types: i.e., Lower Tropical Sal and Mixed Broadleaf Forest, Hill Sal Forest, Chir Pine-Broad Leaved Forest, and Upper Tropical Riverine Forest. In the CHAL, its current distribution includes the moist, shaded slopes and ravine areas and along the river valleys (Figure 11). The model indicates that the range will extend upslope in the Middle Mountain zone.

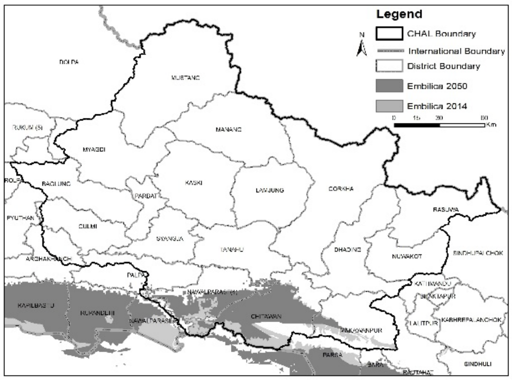

Figure 12: Projected distribution of Embilica in 2050 under the IPCC A2A GHG scenario.

Emblica officinalis. This lowland species associated with the Lower Tropical Sal and Mixed Broad Leaved Forest and Riverine Khair-Sissoo Forest in the Terai and Churia is confined to elevations below 1000 m. The model does not indicate significant range shifts (Figure 12).

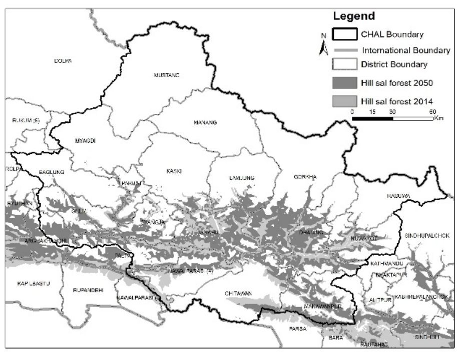

Figure 13: Projected distribution of Sal in 2050 under the IPCC A2A GHG scenario.

Sal, *Shorea robusta*. Sal is widespread in the subtropical and tropical Terai and Churia zones, except where rainfall is very high. The range includes the mid-hill regions along river valleys, even up to 1500 m in some places. Sal prefers climatic conditions with 1000 to 2000 mm of annual precipitation and a dry season less than 4 months (Tewari, 1995). The species is associated with Hill Sal Forest and the Lower Tropical Sal and Mixed Broadleaf Forest. Sal is replaced by *Dalbergia sissoo* and *Acacia catechu* along the waterlogged, riverine areas of the Terai. In the CHAL, the Hill Sal forests occur along the Churia hills and the lower slopes of major river valleys (Figure 13). The model indicates that the Hill Sal forests will move further northwards and upslope into the Middle Mountain zone along the river valleys. Thus, reforestation of higher slopes in catchments can include Sal, along slopes with <2000 mm of rainfall and no frost.

Other species associated with Sal. The forest types (Hill Sal Forest, Lower Tropical Sal and Mixed Broadleaf Forest) that support Sal also includes tree species, as described below, that can be important for forest restoration in climate change-integrated programs.

Karma, *Adina cordifolia*. This species is sympatric with Sal in the forests of the Terai and Churia, but the elevational range distribution is only up to about 800 m; thus, the upslope range extension in response to climate change may be more limited than Sal. The wind dispersed seeds are carried long distances and germinate with early rains, including on bare ground in areas of landslides and abandoned agricultural areas. Thus, natural colonization and regeneration could be encouraged in areas to which the species is adapted. Jamun, *Syzygium cumini*. This species is sympatric with Sal in both the Terai and Churia. It prefers clay-loam or sandy alluvial soils and swampy areas, especially along water courses, and is therefore, more tolerant of wetter environmental conditions than Sal. The tree is also shade-tolerant.

Saj, *Terminalia alata*. This species is associated with the same forests that support Sal, but grows better on deep, alluvial soils around swampy areas. The elevation range (~200 to 1400 m) is similar to Sal; thus the spatial shift in response to climate change scenarios may be similar, except that Saj will likely do better on wetter, less well drained soils.

Siris, *Albizia lebbeck*. This species is associated with the Hill Sal Forest and the Lower Tropical Sal and Mixed Broadleaf Forest. Although it is distributed up to about 1200 m, Siris is more common in the lower elevations, and also along rivers in the *Dalbergia sissoo-Acacia catechu* forests. The macro-scale spatial expansion of Siris in response to climate change could be similar to Sal. Because of its colonizing abilities, the species can be used to restore degraded soils.

How climate models can inform forest restoration in Nepal

Correlative climate models have been used extensively to assess and predict responses of species to climate change, but most commonly used climate models use coarse-scaled global or regional datasets and are also too simplistic to represent all ecological and anthropogenic variables that can influence climate trajectories, environmental conditions, local and microclimatic variations, and other drivers of change to accurately predict future ecological scenarios (Pearson and Dawson, 2003). While mechanistic or process-based models that use ecophysiological and other biological information to assess the responses of species to climate change can provide some triangulation to assess the outputs of correlative models, the necessary information for most species is unavailable (Chmura et al., 2011). However, model-based predictions do provide some information and direction to assess the potential future risks and opportunities that allow conservationists, managers, and practitioners to make better, informed decisions for proactive adaptation strategies, including assisted migrations for forest restoration (Pedlar et al., 2012, Williams and Dumroese, 2013) by narrowing the scope of the possible trajectories (Bellard et al., 2012; Parmesan et al., 2011; Pearson and Dawson, 2003; Pereira et al., 2010).

In a complex environment such as the Himalaya, the highly dissected landscape also presents a myriad topographic variations that create a range of climates and micro-climates, both spatially and temporally. This variation—decoupled from landscape-scale variation—also affects plant survival and persistence. The climate envelope outputs from GCM-based climate envelopes are too coarse to discern and reflect these micro-, and even meso-scale, variations. An analysis of climate resilience using GCM-based models combined with terrain-based analysis has shown the presence of scattered forest patches that would remain resilient to climate change (Jung Thapa et al., 2014. These include microrefugia along steep-sloped ravines, valleys, and north and northwest-facing slopes where there may not be much change in the vegetation communities in the future. Thus, restoration programs in these macro and microrefuge areas can choose the current species assemblages.

The current model outputs of future species distributions can provide some indication of where these important species could grow, and inform reforestation programmes. They can also inform landscape-scale conservation plans that include climate corridors that enable forest trees to shift ranges under future climate scenarios, and reach higher, cooler areas through natural dispersal. Overall, the climate modelling used here indicates that several important tree species in Nepal could exhibit range shifts due to climate change, with an overall trend for tree species to move further northwards or upslope. In the former, the tree species ranges will shift along river valleys which cut through the terrain or move up and down successive east-west running ridges in the Churia, Middle Mountains and High Mountains. The latter route means that species may have to migrate up long hot, dry south-facing slopes, and down shorter, cooler and damper north-facing slopes, to reach progressively higher areas. River valleys would be an easier option, but in many of them forests have been cleared for agriculture, settlements and infrastructure, and the corridors are fragmented. Thus, restoring north-south corridors should be a high priority in landscape and forest management.

Even with the presence of climate corridors, range shifts among long-lived tree species into climate refugia will require long time periods causing the species shifts to lag behind climate change, which is now occurring at an accelerated pace (Bertrand et al., 2011, Duveneck and Scheller 2015, IPCC 2007). This will be particularly serious for slow-maturing tree species with short seed dispersal distances. Thus, in order to maintain forest cover and ecosystem services, 'assisted migration', where tree species that are expected to exhibit range shifts in response to climate change can be planted in their potential future habitats, has been recommended as a strategy for climate change-integrated forest management (Gray et al., 2011; Marris, 2009; Pedlar et al., 2012; Williams and Dumroese, 2013). Selecting the species for assisted migration can be informed through analyses such as this, that provide predictive information about species range shifts based on climate change projections.

Conclusion

As local environmental conditions become unfavourable, some species may become extirpated, especially if the forests are fragmented and climate corridors are lost, with consequent loss of species diversity. Degraded forests are more vulnerable to climate change-related impacts. Forest degradation will also affect ecosystem services that support human communities, such as natural resource provision, water supplies and crop pollination. While avoiding degradation of intact forest systems that is obviously a better strategy to pursue, increasing biodiversity in plantations, and in naturally regenerated or semi-natural forests can increase resilience, and even carbon storage capacity (Thompson et al., 2009). Such restoration programs should strive to emulate natural forests through analogue forestry (Senanayake and Jack, 1998), using multiple species to increase both response and functional diversity within the ecosystem. Restoration should also prioritize strategic areas that are most ecologically sensitive, that will help to improve ecosystem process and services, and that contribute towards sustainable socioeconomic development solutions (Benayas et al., 2009). In a landscape or basin-wide spatial context, the diversity of the mosaic comprised of intact, restored, and sustainable-use forests will also increase resilience through multiple redundant and reinforcing ecological processes (Elmqvist et al., 2003; Peterson, Allen, and Holling, 1998).

Recommendations

Nepal's steep mountain slopes have been extensively degraded from centuries of anthropogenic forest conversion and clearing, but the intensity of use has accelerated during the past half-century. Community re-engagement and stewardship in forest management for better management over the last few decades is now helping significantly to restore forest cover especially in the middle mountains. However, global climate change is now beginning to change forest communities. Thus, forest management and restoration strategies should consider the impacts of climate. Analyses such as this, while not perfect, can help to make informed decisions about long-term forest restoration programs that integrate climate change, instead of ad hoc forest restoration programs.

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