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Research paper

The changing land cover and fragmenting forest on the Roof of the World: A case study in Nepal's Kailash Sacred Landscape

Kabir Uddin[a], Sunita Chaudhary[a], Nakul Chettri[a,*], Rajan Kotru[a], Manchiraju Murthy[a], Ram Prasad Chaudhary[b], Wu Ning[a], Sahas Man Shrestha[c], Shree Krishna Gautam[d]

[a] International Centre for Integrated Mountain Development (ICIMOD), GPO Box 3226, Kathmandu, Nepal
[b] Research Centre for Applied Science and Technology, Tribhuvan University, Kirtipur, PO Box: 1030, Kathmandu, Nepal
[c] Department of Forests, Babar Mahal, PO Box: 23200, Kathmandu, Nepal
[d] Forest Resources Assessment Nepal, Babar Mahal, PO Box: 23200, Kathmandu, Nepal

HIGHLIGHTS

- Temporal change in land cover and forest fragmentation were analyzed.
- The results showed 9% decrease in forest cover and 12% increase in cropland.
- A further 4% decline in forest cover and 5% increase in cropland were predicted.
- 10% decrease in large core forest and 10.6% decline in core forest was predicted.
- Expansions of cropland coupled with high dependency on forests are the drivers.

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ABSTRACT

Land cover change is one of the most important drivers of forest ecosystem change. The Hindu Kush Himalayan region (HKH) has experienced severe forest degradation but data and documentation are limited. We undertook this study in the Nepalese part of the Kailash Sacred Landscape (KSL), an important transboundary region known for its biodiversity and the scared values. Forest is an important ecosystem within the landscape and provides various goods and services including habitat for many keystone species. However, precise information on forest change and overall land cover change in the area is limited. We analyzed land cover change and forest fragmentation between 1990 and 2009, and the predicted change for 2030. There was a 9% decrease in forest cover and 12% increase in cropland between 1990 and 2009. A further 4% decline in forest cover and 5% increase in cropland was predicted by 2030, together with a slight increase in grassland and barren area. Fragmentation analysis showed a 10% decrease in large core forest between 1990 and 2009, accompanied by an increase in patch forest. A further 10.6% decline in core forest was predicted by 2030, accompanied by an increase in patch, perforated, small-sized core, and mediumsized core areas. The study suggests that expansions of cropland coupled with high dependency on forests are the major drivers of the observed forest change. Recommendations are made based on the results of the study that will help to maintain and restore forest, and support biodiversity conservation and livelihoods.

1. Introduction

Around 75% of the natural forested areas across the world have either been cleared or dominated by human activity since the last ice age (Ellis & Ramankutty, 2008). The global rate of forest loss is currently reported to be 0.6% per year (Hansen, Stehman, & Potapov, 2010). Forest degradation as a result of resources extraction, and conversion of forested areas to cropland, settlement and other land use types is leading to forest fragmentation (Crooks, Burdett, Theobald, Rondinini, & Boitani, 2011), a decrease in productivity (Hijmans, Cameron, Parra, Jones, & Jarvis, 2005), an increase in forest isolation (McGarigal & Cushman, 2002), and changes in community composition (Saunders, Hobbs, & Margules, 1991). Studies have shown that, if not controlled, natural old-growth forests can be critically fragmented to the point at which they can neither maintain viable populations of flora and fauna, nor maintain their

* Corresponding author. Tel.: +977 9841516138.
E-mail address: Nakul.Chettri@icimod.org (N. Chettri).

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ecological integrity (Kettunen, Terry, Tucker, & Jones, 2007). Forest fragmentation, in which the forest is reduced to patches, can have a marked detrimental impact on biodiversity. Among others, it can result in homogenization (Lôbo, Leão, Melo, Santos, & Tabarelli, 2011), reduction in habitat quality for forest-interior species, and loss of forest health due to changes in microclimate and increased susceptibility to edge predators, parasites, and invasive species (Thuiller, Albert, Araújo, Berry, & Cabeza, 2008). Rare and patchily distributed species that require a larger range of a specific habitat are particularly affected by fragmentation (Fenoglio, Srivastava, Valladares, Luciano, & Salvo, 2012).

Apart from the impact on biodiversity, fragmentation can also negatively impact ecosystem processes and the flow of ecosystem services (Burkhard, Kroll, Muller, & Windhorst, 2009), which in turn affects the livelihoods of forest dependent communities (Chettri, Sharma, Deb, & Sundariyal, 2002). The fragmentation process may lead to landscape, ecosystem and habitat degradation (Leal, Filgueiras, Gomes, Iannuzzi, & Andersen, 2012; Schleuning, Farwing, Peters, Bergsdorf, & Bleher, 2011), and biodiversity loss (Crooks et al., 2011). Land cover change is becoming so prominent at a global scale that it is significantly affecting the Earth's ecosystems and functions (Lawler et al., 2013). By 2100, the impacts of land cover change on biodiversity at a global scale is likely to be more significant than climate change, nitrogen deposition, species introductions, and changing atmospheric concentrations of carbon dioxide (Sala et al., 2000).

The Hindu Kush Himalayan region (HKH) extends over more than four million square kilometers and includes all of Bhutan and Nepal and parts of six other countries: Afghanistan, Bangladesh, China, India, Myanmar, and Pakistan. It is the source of ten large Asian river systems – the Amu Darya, Indus, Ganges, Brahmaputra (Yarlungtsanpo), Irrawaddy, Salween (Nu), Mekong (Lancang), Yangtse (Jinsha), Yellow River (Huanghe), and Tarim (Dayan), – and provides water, ecosystem services, and the basis for livelihoods to a population of around 210.53 million people in the region. The basins of these rivers provide water to 1.3 billion people, a fifth of the world's population (Schild, 2008). Endowed with a rich variety of gene pools and species, and ecosystems of global importance (Chettri, Shakya, Thapa, & Sharma, 2008), the region hosts parts of four Global Biodiversity Hotspots: Himalaya, Indo-Burma, Mountains of South-West China, and Mountains of Central Asia (Mittermeier et al., 2004). Approximately 39% of the HKH is comprised of grassland, 20% forest, 15% shrub land, and 5% agricultural land. The remaining 21% are barren land, rocky outcrops, built-up areas, snow cover, and water bodies (Chettri et al., 2008). With 20% coverage, forest is one of the most important ecosystems in terms of habitat for flagship species (Chettri, Sharma, & Zomer, 2012; Kandel et al., 2015) and as a source of provisioning, regulatory, cultural and supporting services (Badola et al., 2010; Kubiszewski, Costanza, Dorji, Thoennes, & Tshering, 2013; Pant, Rasul, Chettri, Rai, & Sharma, 2012). However, the region has witnessed significant deforestation in the past (Ives & Messerli, 1989) which is still ongoing in many areas (Pandit, Sodhi, Koh, Bhaskar, & Brook, 2007). Although the HKH has witnessed significant progress in conservation, with 39% of land in protected areas (Chettri et al., 2008), the region is still facing challenges with the effectiveness of protected area management (Oli, Chaudhary, & Sharma, 2013), and protected areas are often isolated as conservation islands (Chettri et al., 2008). The conservation agenda is facing additional challenges with climate change (Singh, Singh, & Skutsch, 2010) and high rates of absolute poverty in some parts (Gerlitz, Hunzai, & Hoermann, 2012). Moreover, the region is poorly researched and the information available on biodiversity, land cover change, and climate change is far less than required. The fourth and fifth reports of the Intergovernmental Panel on Climate Change (IPCC) explicitly pointed to the HKH as a data deficit area (IPCC, 2007, 2014; Solomon

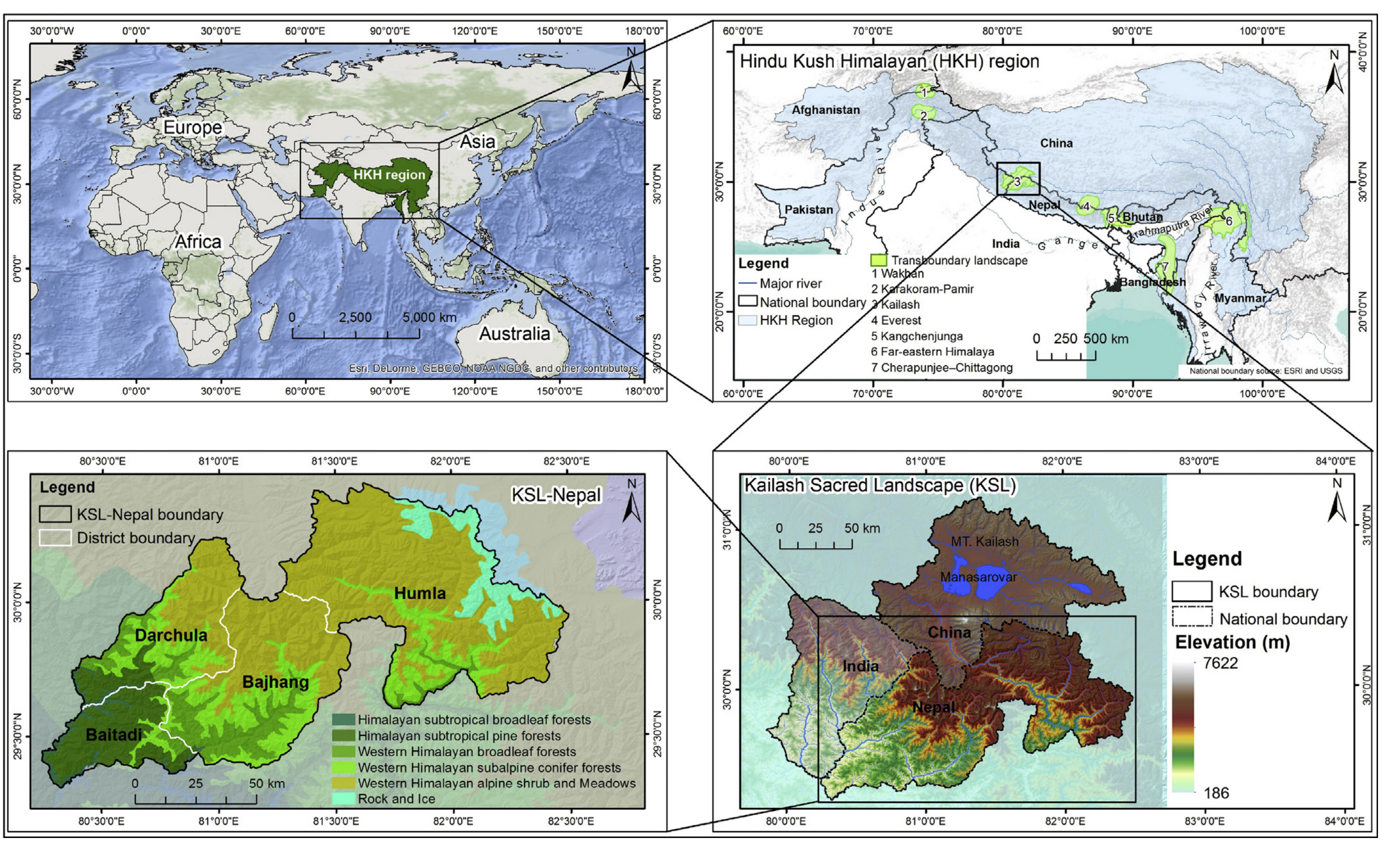

Fig. 1. Map showing the Hindu Kush Himalayas in the global set and Kailash Sacred Landscape and the study area of Nepalse part of the landscape along with its ecoregions.

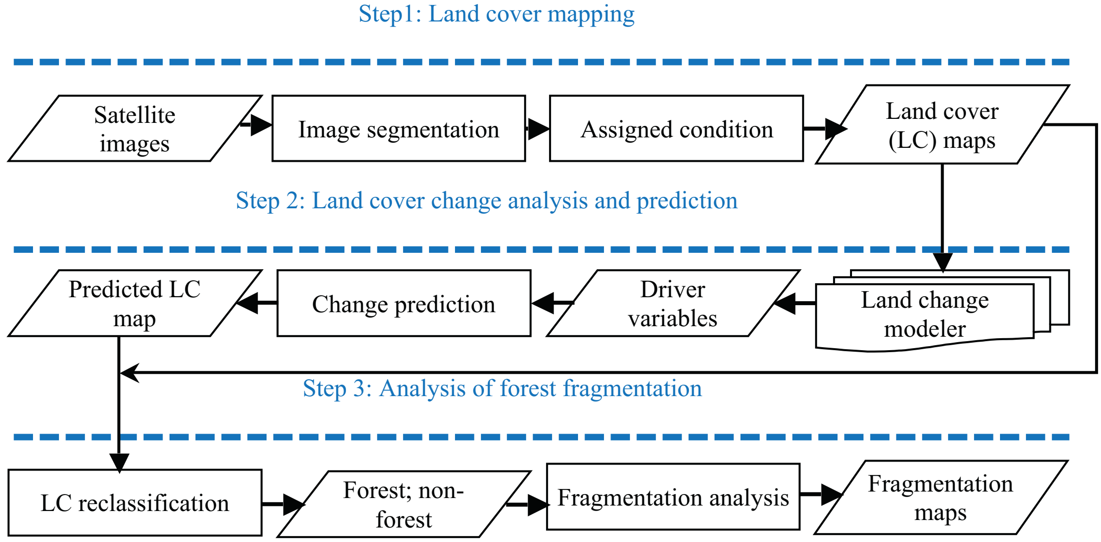

Fig. 2. Overall methodological framework for the study.

et al., 2007). There is an urgent need to address these challenges through sustainable landscape planning, management, and development, and this will be crucial for the millions of people living in the HKH (Ives & Messerli, 1989; Schild, 2008) as well as the billions living in the downstream of the ten river basins.

Transboundary landscape-level planning and management for biodiversity conservation, where initiatives are taken beyond the political boundaries for common conservation and develop goals, is an evolving concept in the HKH (Chettri, Sharma, Shakya, & Bajracharya, 2007; Zomer & Oli, 2011), which emerged primarily out of recognition that protection of protected areas (national parks, sanctuaries, wildlife reserves) is essential but insufficient as a biodiversity conservation strategy (Sharma, Chettri, & Oli, 2010). Almost one-third of the protected areas are transboundary, (Chettri et al., 2008) and in these areas, as elsewhere in the HKH, ecosystems and habitats extend across political boundaries. This means that landscape level planning is necessary and management requires regional cooperation if the ecosystems or habitats are transboundary in nature (Sharma, Chettri, Gurung, & Shakya, 2007). Seven transboundary landscapes have been identified across the HKH based on biodiversity significance, representation of ecoregions, cultural significance, and contiguity of ecosystems for conservation and sustainable development of the region (Chettri, Sharma, & Thapa, 2009), and are being used to develop transboundary landscape level planning and management approaches (Fig. 1).

The Kailash Sacred Landscape (KSL) is one of the seven landscapes. It covers parts of far-western Nepal, the central Indian Himalayas, and Tibet Autonomous Region (TAR) of China. A transboundary collaborative programme was established in 2010 between China, India and Nepal to conserve ecosystems and biodiversity in the landscape, while encouraging sustainable resources management (Chettri et al., 2009). The landscape is named after the most prominent feature, Mount Kailash (6714 m) in the TAR, one of the most sacred mountains in Asia (Brockman, 2011). The landscape has a strong cultural connection with India and Nepal as a gateway to Mount Kailash, and is famous for its ancient heritage and religious significance for Hindu, Buddhist, Bon Po, Jain, Sikh, and other religions, following traditions that go back millennia (Adler et al., 2009). The landscape is also home to 93 mammal species, 497 bird species, and 134 fish species among other fauna making it one of the richest areas in the western Himalayas (Zomer & Oli, 2011). Four of Asia's great rivers have their source in the landscape, the Indus, Brahmaputra, Karnali, and Sutlej, providing essential transboundary ecosystem goods and services, both locally and downstream (Zomer & Oli, 2011).

The Nepalese part of the KSL (KSL—Nepal hereafter) covers 13,289 square kilometers (42% of the total area) and covers four mountain districts (Darchula, Humla, Baitadi, and Bajhang) in the far-west of the country. This is one of the most underdeveloped regions of Nepal and faces numerous conservation and development challenges resulting from the harsh climate, poor accessibility, marginality, and high level of poverty, which manifests in a high dependency on natural resources leading to overexploitation (Kunwar, Mahat, Acharya, & Bussmann, 2013; Roy, Schmidt-Vogt, & Myrholt, 2009). Forest plays a vital role in supporting the rural livelihoods in the area. However, poverty driven human pressure is impacting on the existing forest ecosystem and leading to habitat fragmentation, ecosystem degradation, and a decrease in the capacity to provide ecosystem services (Uddin et al., 2015; Zomer & Oli, 2011). Information on the forest status and trends in the area is limited, and there is no cohesive framework available for regular assessment and monitoring of change across the landscape. Even basic questions such as what are the changes in land cover and what is the rate of forest change remain unanswered. Understanding the land cover change, especially forest change and fragmentation, is urgently needed both to understand past development and as a basis for landscape level planning to guide future conservation and development management interventions. The present study was designed to fill this gap and provide the first detailed information about forest change in the landscape. The main questions for the research were:

1. How is the forested ecosystem of the landscape changing over time?
2. How is forest fragmentation contributing to the trend of forest ecosystem change?
3. What recommendations can be made for conservation interventions in the landscape?

2. Study area

KSL—Nepal is located between 80°24′E to 82°49′E and 29°30′N to 30°44′N and covers an area of 13,289 square kilometers, with an elevation ranging from 518 to 7132 m above sea level (Fig. 1). The study area is situated at the junction of the Western Himalayan, Eastern Himalayan, and Central Asiatic regions and is part of the

Table 1
Satellite images used in the analysis.

Date	Satellite	Sensor	Path	Row
26/11/2009	IRS P6	LISS III	099	50
26/11/2009	IRS P6	LISS III	100	50
21/10/1992	Landsat	TM	143	39
23/10/1990	Landsat	TM	144	39
23/10/1990	Landsat	TM	144	40

Himalaya Biodiversity Hotspot (Mittermeier et al., 2004). The area has five major ecoregions: Himalayan subtropical broadleaf forest, Himalayan subtropical pine forest, Western Himalayan broadleaf forest, Western Himalayan subalpine conifer forest, and Western Himalayan alpine shrub and meadows (Olson et al., 2001). It is significantly rich in biodiversity with 22 mammals, 12 birds, and 1 reptile listed on the IUCN Red List; 8 mammals, 7 birds, 22 reptiles, and 8 fish endemic to the region; and 35 species of mammals and 73 species of birds listed by the Convention on International Trade in Endangered Species (CITES). Globally threatened species such as snow leopard (*Uncia uncia*) and Himalayan musk deer (*Moschus chrysogaster*) inhabit the area. The total human population in 2001 was approximately 564,000. Agriculture is the main occupation for over 70% of the population (Zomer & Oli, 2011). About 22% of the land is covered by forest which is a major source of fuel, fodder and timber among other and play an important role in supporting the subsistence livelihoods. Deforestation is prominent and the demand for forest land for agriculture and rural infrastructure such as roads, electricity, water supply, hospitals, and schools is quite high. Timber harvesting and export has been identified as a major concern, with 3000 cubic meters of timber per annum supplied officially to China and India and an unknown additional amount traded illegally. Shifting cultivation is still practiced with short rotation period (Zomer & Oli, 2011). The fragile nature of the area, unsustainable resources harvesting, coupled with development activities pose a serious threat to the forested ecosystems in the landscape, with implications for biodiversity and people.

3. Methods

Fig. 2 shows the overall methodological framework. Briefly, land cover maps were developed for the landscape for 1992 and 2009 using object based image analysis of satellite images. Land use and land cover change was then analyzed from the maps using standard software, and a map of potential land cover in 2030 prepared based on the past change and variables taken as drivers. Finally, all the land cover maps were analyzed to detect forest fragmentation. The details of the procedures and reasons for use are given in the following sections.

3.1. Analysis of land use and cover change (LUCC)

Land use and land cover change (LUCC) maps were prepared for the landscape for 1990 and 2009 using medium resolution spatial images from Landsat thematic mapper (TM) (1990/1992) and linear imaging self-scanning sensor (LISS III) (2009) (Table 1). The images were collected at the same time of year to avoid problems of seasonal variation. A hierarchical land cover classification system (LCCS) was used (Table 2) following Gregorio (2005).

Preprocessing of the satellite images was carried out prior to image classification to bring the images into a standard projection so that they could be overlaid. Ground control points (GCP) were generated from the Landsat TM images and used for geometric correction of the IRS LISS-III images into Universal Transverse Mercator (UTM) Zone 44. The images were then re-sampled using a convolution algorithm to a common resolution of 30 m.

Object-based image analysis (OBIA) was performed using eCognition developer software to derive homogeneous image objects through segmentation. OBIA provides a methodological framework for machine-based interpretation of complex classes using both spectral and spatial information and generates better classification results with a higher degree of accuracy than pixel-based methods (Chettri, Uddin, Chaudhary, & Sharma, 2013; Lang et al., 2011; Uddin et al., 2015). Finally, a multi-resolution segmentation algorithm was applied in which homogeneous areas resulted in larger objects and heterogeneous areas in smaller ones. The algorithm helps to merge pixels with their neighbors based on relative homogeneity criteria (Baatz, Arini, Schäpe, Binnig, & Linssen, 2006). Several segmentations were tested using different parameters until a satisfactory result was obtained.

Information on the spectral values of image layers, vegetation indices (Normalized Difference Vegetation Index, NDVI and Normalized Difference Snow and Ice Index, NDSII), and a land water mask was used in the analysis. The layers were created through band rationing, slope, and texture information. Objects with an area smaller than the defined minimum mapping units were merged with other objects (Bajracharya, Uddin, Chettri, Shrestha, & Siddiqui, 2010). Initially sixteen different land cover types were used in the classification process, which were then merged to give a land cover map with seven broad categories. The categories are shown in Table 2. The classified land cover map and forest layers were exported to raster file format for land use and cover change (LUCC) and forest fragmentation analysis. The accuracy of the land cover map was assessed by selecting 250 stratified pixels at random in a Google Earth image as reference, and ascertaining the accuracy of the classification in a field survey using a global positioning system (GPS) to locate the points. The overall accuracy was 84.8% in 1990 and 88.4% in 2009.

Table 2
Land cover in KSL—Nepal in 1990, 2009, and 2030 (predicted).

Land cover	1990		2009		2030		Change (1990–2009)	Change (2009–2030)
	ha	%[a]	ha	%[a]	ha	%[a]	%[b]	%[b]
Forest	324,327	24.4	296,257	22.3	284,540	21.4	−8.7	−4.0
Shrub land	7223	0.5	6552	0.5	5760	0.4	−9.3	−12.1
Grassland	273,673	20.6	295,483	22.2	298,532	22.5	+8.0	+1.0
Crop land	187,802	14.1	210,189	15.8	219,649	16.5	+11.9	+4.5
Total vegetated	*793,025*	*59.6*	*808,481*	*60.8*	*808,481*	*60.8*	*+1.9*	*0*
Barren area	237,413	17.9	290,427	21.9	290,427	21.9	+22.3	0.00
Water bodies	2443	0.2	2443	0.2	2443	0.2	0.0	0.00
Snow/glacier	295,984	22.3	227,514	17.1	227,514	17.1	−23.1	0.00
Total non-vegetated	*535,840*	*40.4*	*520,384*	*39.2*	*520,384*	*39.2*	*−2.9*	*0.00*
Total	1,328,865	100	1,328,865	100	1,328,865	100		

[a] Percentage of total area of KSL—Nepal.
[b] Percentage change in component.

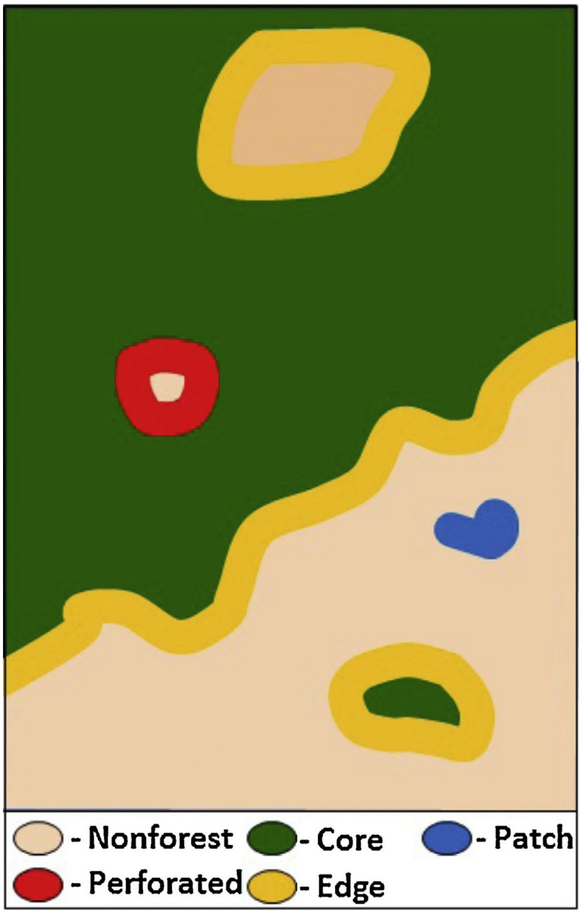

Fig. 3. Diagrammatic representation of fragmentation classes.

3.2. Land use and cover change (LUCC) analysis and modeling

The change in land use and land cover (LUCC) was analyzed to depict gains and losses in graphical form. LUCC modeling was carried out using Land Change Modeler (LCM) in IDRISI Taiga software from Clark Labs (Eastman, 2009), which is a well known software for LUCC analysis (Frey & Paul, 2012; Fu et al., 2005). LCM uses the feed-forward concept of a multi layer perception neural network and follows the artificial neural network modeling technique (Atkinson & Tatnall, 1997). LCM has three basic elements: change analysis, transition potential modeling, and change prediction. The change analysis panel provides a rapid quantitative assessment of change by visualizing gains and losses from different land cover categories; transition potential modeling, or net change, shows the results of considering the original land cover areas adding gains, and subtracting losses; and change prediction examines the contributions to change experienced by a single class of land cover. The land cover maps for 1990 and 2009 were imported into IDRISI Taiga in a raster (IDRISI raster) format. Differences in the maps were reviewed and assessed with LCM to visualize and quantify land cover changes. LCM was then used for empirical modeling of land cover change. The dominant transitions from past land cover change were identified, and related to land cover transitions in order to link with drivers of change. Slope and infrastructure development were considered as major drivers of deforestation in the change analysis. Slope can affect LUCC, as forest in flatter and more fertile areas is more likely to be cleared for agriculture; and infrastructure development is related to urbanization and an increase in built-up area, which may lead to an increase in

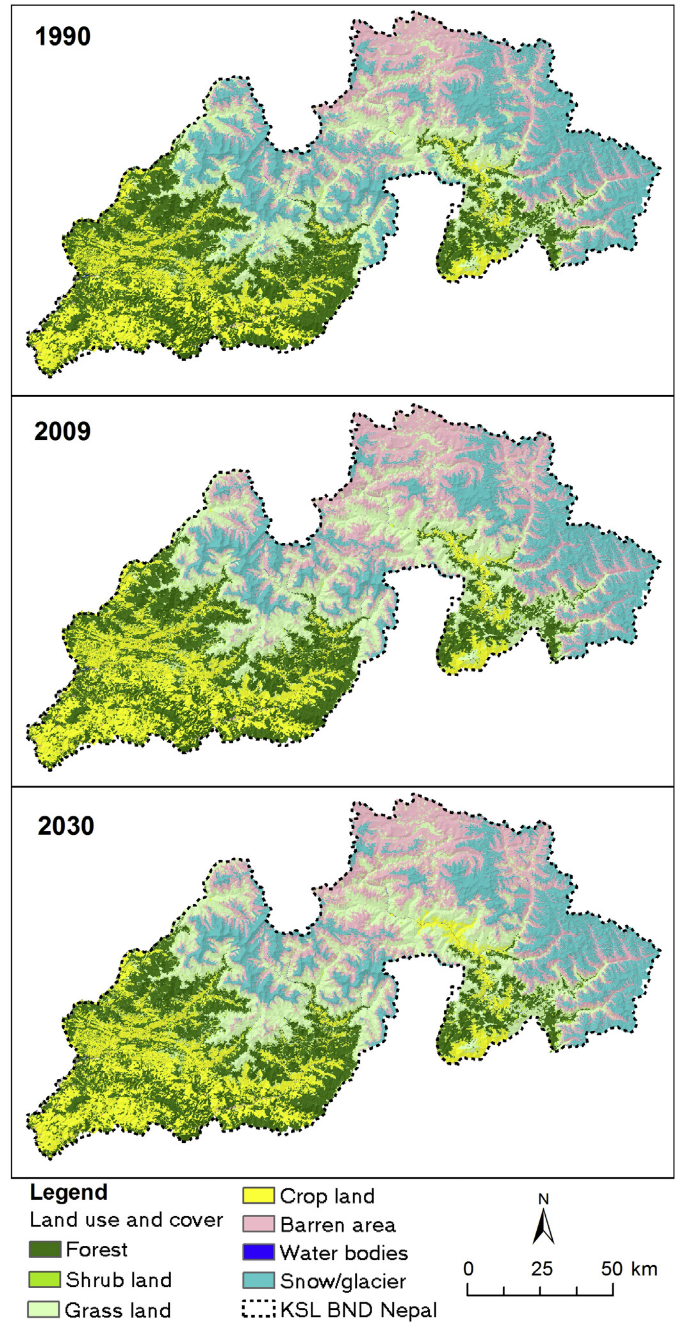

Fig. 4. Land cover of the Kailash Sacred Landscape—Nepal for 1990, 2009, and 2030.

agricultural land at the expense of forest area. Based on this concept, maps of ‘distance-to-roads’ and ‘distance-to-slope’ were produced using the ‘Euclidean Distance’ tool in ArcGIS. These maps were imported to IDRISI raster format and the drivers were incorporated in the LCM as explanatory driver variables of change for a particular transition. A map of potential land areas that will go through transitions was created to predict changes. The prediction year was specified as 2030, and predictions were examined using the change prediction tab. Predictions were also examined taking into consideration the possible interventions, especially within conservation and development projects. The analyzed land cover map for 2030 was then exported for forest fragmentation analysis.

Table 3
Land cover change matrix for KSL—Nepal 1990 to 2009.

Land cover (ha)	Forest	Shrub land	Grassland	Crop land	Barren area	Water bodies	Snow/glacier	Total (1990)
Forest	296,257	750	9845	17,475	0	0	0	324,327
Shrub land	0	5802	1208	213	0	0	0	7223
Grassland	0	0	268,974	4699	0	0	0	273,673
Crop land	0	0	0	187,802	0	0	0	187,802
Barren area	0	0	0	0	237,413	0	0	237,413
Water bodies	0	0	0	0	0	2443	0	2443
Snow/glacier	0	0	15,456	0	53,014	0	227,514	295,984
Total (2009)	296,257	6,552	295,483	210,189	290,427	2,443	227,514	1,328,865

3.3. Assessment of forest fragmentation

The ArcGIS Landscape Fragmentation Tool was used to study forest fragmentation and edge effects as described by Vogt et al. (2007). The method is based on a procedure to map forest fragmentation based on forest and non-forest land cover; the tools quantify forest fragmentation from raster land cover maps. The land cover maps for 1990 and 2009 and predicted land cover map for 2030 were reclassified into forest and non-forest classes using ArcGIS spatial analyst. GIS was used to identify patch formation within the extended forests, including edge and perforated areas, and intact and contiguous forested areas (Fig. 3), and assign them to a patch size class as described by Stokes and Morrison (2003). Using a specified edge width of 100 m, forest fragmented areas were classified into 'core' forest—relatively distant from the forest-non forest boundary; 'patch' forest—forests too small to be considered as core forest; 'perforated' forest—boundaries between core forest and relatively small perforations; and 'edge' forest—boundaries of relatively large perforations and the exterior boundaries of core forest regions (Vogt et al., 2007). 'Core' forest was further divided into 'small core' (<101.17 ha), 'medium core' (101.17–202.34 ha), and 'large core' (>202.34 ha) areas.

4. Results

4.1. Land use and cover change (LUCC) and prediction

Forest was the dominant land cover in 1990 with 24.4% of the total area of KSL—Nepal, followed by snow and glaciers (22.3%) and grassland (20.6%) (see Table 2). The forest area had decreased by about 9% (28,070 ha) in 2009, to 22% of the total area. Shrubland also decreased by 9.3% (from 7223 ha in 1990 to 5760 ha in 2009), while cropland increased by 12% (from 187,802 ha in 1990 to 210,189 ha in 2009). Other major changes were a 22.3% increase in barren area and a 23.1% decrease in snow/glacier area. The land cover distribution and changes are shown in Table 2 and Fig. 4. The conversion of land cover between different classes between 1990 and 2009 is shown in the form of a land cover change matrix in Table 3. There was a major change from forest to cropland (17,475 ha) and forest to grassland (9845 ha), from grassland to cropland, and from snow/glacier to barren land. No area was converted to forest.

The predictions for 2030 showed a further loss of 4% of forest cover (5320 ha converted to grassland and 6465 ha to cropland), a 5% increase in cropland, and a slight increase in grassland (Tables 2 and 4). No significant area was converted into forest. Predictions of land cover change (2009–2030) that included interventions that could halt the present rate of deforestation and restore degraded forests showed a 1% increase in forest area. The spatial distribution of land cover for 2030 is shown in Fig. 4.

4.2. Forest fragmentation and prediction

The distribution of forest fragmentation showed significant changes between 1990 and 2009, and further change to 2030. In 1990, large core forest was dominant covering 60% of the forest area; edge forest covered 28%, small core 5%, perforated 3.8%, medium core 1.7%, and patch forest 1.5%. In 2009, large core decreased by 10% and perforated forest by 58%, while medium core, small core, edge, and patch forest increased by 6%, 12%, 1.8%, and 26.7%, respectively.

By 2030, the area of large core was predicted to decrease by a further 10.6%, while medium core was predicted to increase by 39%, small core by 14.3%, perforated by 250% (to 30% more than the 1990 value), edge by 0.6% and patch by 10.5%. The details are shown in Fig. 5 and the values are summarized graphically in Fig. 6.

5. Discussions

5.1. Land use and cover change, and prediction

Overall, the vegetated area in KSL—Nepal is decreasing and non-vegetated area is increasing. The results are in line with the report by Pandit et al. (2007). Land use and cover change is now recognized as one of the most important drivers of global change (Lambin et al., 2001). The overall changes are likely to have a negative impact on biodiversity, ecosystem services, and the subsistence livelihoods of the people living in the region (Hofer & Messerli, 2006; Myers, 1986). The biodiversity is of global significance, especially endemic and endangered species such as Himalayan musk deer (*Moschus leucogaster*) and Asiatic black bear (*Ursus thibetanus*), which would be strongly affected by loss of contiguous forest habitat. Zomer and Oli (2011) has already identified forest degradation as one of the

Table 4
Land cover change matrix for KSL—Nepal 2009 to 2030 (predicted).

Land cover (ha)	Forest	Shrub land	Grassland	Crop land	Barren area	Water bodies	Snow/glacier	Total (2009)
Forest	284,472	0	5320	6465	0	0	0	296,257
Shrub land	3	5760	677	112	0	0	0	6552
Grassland	0	0	292,535	2948	0	0	0	295,483
Crop land	65	0	0	210,124	0	0	0	210,189
Barren area	0	0	0	0	290,427	0	0	290,427
Water bodies	0	0	0	0	0	2443	0	2443
Snow/glacier	0	0	0	0	0	0	227,514	227,514
Total (2030)	284,540	5,760	298,532	219,649	290,427	2,443	227,514	1,328,865

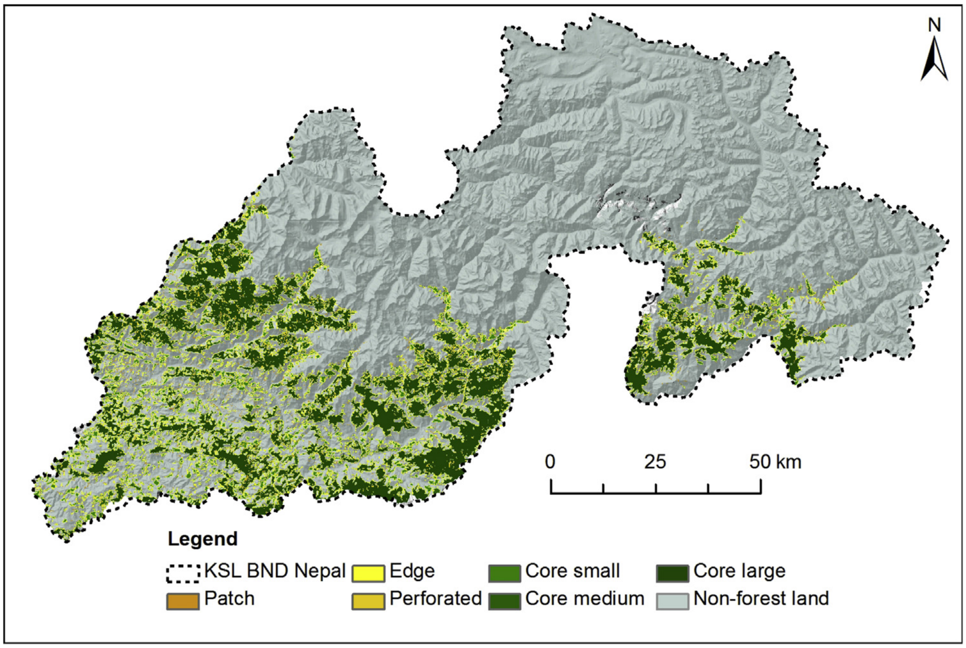

Fig. 5. Forest fragmentation map 2030 (predicted).

major reasons for biodiversity loss in the Himalayas. The area of KSL—Nepal includes global biodiversity hotspots, important ecoregions, and the headwaters of major rivers, thus the rate of forest change is a matter of global, as well as national and regional, concern. The ecosystem services provided by KSL—Nepal could be at risk. As more than 90% of the population depends on forests for fuelwood and other products this will have a significant impact on livelihoods. The local communities are highly dependent on forest resources and already face challenges in sourcing fuelwood, fodder, and timber (Zomer & Oli, 2011), which will be further exacerbated by a decline in forest cover, thus increasing poverty in the area.

The results suggest that expansion of cropland is one of the major drivers of land cover change, as also reported elsewhere in the Himalayas (Alam, Rashid, Bhat, & Sheikh, 2011; Bawa & Seidler, 2015). In KSL Nepal, more than 70% of population is dependent on agriculture (Zomer & Oli, 2011) and the predictions indicate a further increase in cropland and decrease in forest. However, when interventions that supported forest conservation were included in the model, there was an increase in forest area. This indicates that landscape planning in the area should focus on interventions to conserve forest, and thus maintain the rich biodiversity and flow of ecosystem services and secure local livelihoods as suggested by Bawa and Seidler (2015). Loss of forest is particularly serious in

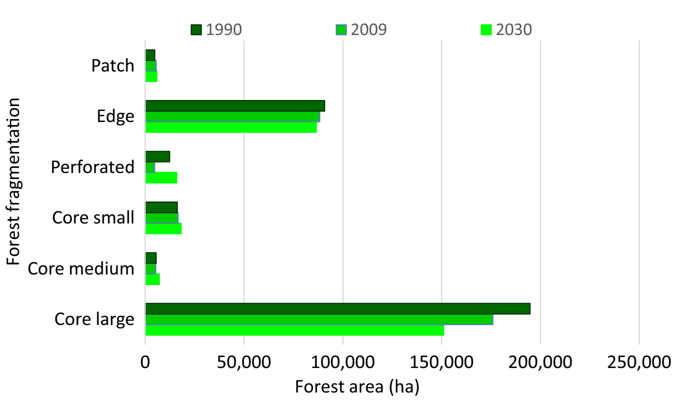

Fig. 6. Forest fragmentation and change in KSL Nepal.

a mountainous area like this, where the landscape is fragile with steep slopes and high elevation, and loss of soil cover can mean that recovery of the ecosystem can be very slow or even impossible (Halada, 2010).

Land cover change studies are crucial for developing effective plans for natural resource management (Gilani et al., 2015). A similar study conducted in the mountains of the Peruvian Andes also identified the need for land cover change assessment for conservation planning (Kintz, Young, & Crews-Meyer, 2006). The present study is the first of its kind in this area and provides a baseline for planned conservation and development planning and interventions. The results will not only help to fill the data gap for Nepal and the HKH region, they will also contribute to better understanding of global change and underlying causes, as the global data on land cover change is poor (Turner, Meyer, & Skole, 1994), and the need to conduct land cover assessment at a local scale, especially in developing countries, has been put emphasised by several studies (Lambin et al., 2001; Loveland et al., 2000; Vadrevu, Justice, Prasad, Prasad, & Gutman, 2015).

5.2. *Forest fragmentation and prediction*

Forests generally become fragmented through intensification of human activities (Peres et al., 2010). The results of this study suggested cropland expansion as one of the major reasons for the observed fragmentation along with high dependence on forest resources coupled with illegal timber extraction as shown by literature review. Reddy, Sreelekshmi, Jha, and Dadhwal (2013) in India and Millington, Velez-Liendo, and Bradley (2003) in Bolivia also proposed socio-economic processes as a reason for forest fragmentation. Forest fragmentation increased in KSL—Nepal between 1990 and 2009, and was predicted to increase further by 2030: with less core, edge, and perforated forest, and more patches. Similar results have been noted in different geographic zones in India (Reddy et al., 2013); and the Alpine grasslands of Abiseo National Park (Kintz et al., 2006) and elsewhere (Lele & Joshi, 2009; Saikia, Hazarika, & Sahariah, 2013). However, comparable data from the Himalayas is limited, and the studies that have been carried out have used different temporal and spatial scales (Nagendra, Paul, Pareeth, &

Dutt, 2009). Forest fragmentation can have multiple impacts on ecosystem functions (Nagabhatla, Finlayson, & Sellamuttu, 2012), including habitat loss (Fahrig, 2003), change in species abundance (Pardini, de Arruda Bueno, Gardner, Prado, & Metzger, 2010), and overall loss of biodiversity (Biswas & Khan, 2011; Wenguang et al., 2008). The trends and predictions of forest fragmentation together with the land cover change in KSL—Nepal could have a serious impact on the rich biodiversity of the area as well as on cultural, supporting and regulatory services, including the water catchments.

These impacts could be halted in the KSL Nepal if the Kailash Sacred Landscape Conservation and Development Initiative (KSLCDI), which is supporting planning at the landscape level over all three countries, could design interventions that address the issue of forest loss and degradation. Interventions of the type proposed would reverse the decline and enable forest cover to start increasing. Improved understanding of the dynamics of land cover change and forest fragmentation will help resource managers to understand the ecological processes and introduce adaptive and restoration measures (Bharti, Adhikari, & Rawat, 2012; De & Tiwari, 2008; Nagendra, Pareeth, Sharma, Schweik, & Adhikari, 2008). The results of this study provide timely inputs to the implementation of KSLCDI and other interventions. The results will also help governments, non-governmental organizations, and other stakeholders to make decisions and take pro-active action in those areas where the fragmentation trend is marked, to support biodiversity management and safeguard people's livelihoods.

6. Conclusions

Over a period of 19 years, KSL—Nepal has experienced a decrease in forest cover, and an increase in cropland and barren land. Forest cover is likely to decrease further, and cropland to increase, by 2030. The results indicate that forest fragmentation coupled with land cover change may lead to critical forest degradation with implications for biodiversity, ecosystem services, and people's livelihoods. Globally threatened species and species with a limited habitat range, and forest dependent communities, are likely to be most strongly affected. The study further suggests that cropland expansion, high dependency on forest, and illegal timber extraction are the major drivers of forest change and fragmentation. This study fills an information gap in a poorly researched area with poor data availability, improves the information base at national and regional scales, and may contribute to understanding of global change. Such information is required for informed decision making and planning for landscape conservation and development interventions. In particular, the results will be useful for planning landscape connectivity and corridors, which are important for conserving biodiversity and maintaining the flow of ecosystem services. The implementation of conservation and development interventions by the KSLCDI will benefit in particular as the initiative aims to conserve the rich biodiversity and develop the region sustainably. Future research should aim to increase understanding of the indirect drivers that are causing forest fragmentation and agricultural expansion, and the impact on biodiversity and livelihoods. Based on the results of this study, the following recommendations are made:

- extend the study across the entire landscape to see the pattern and processes in the area within other countries and design complementary interventions;
- promote landscape connectivity and an ecological network through reforestation and restoration of non-forested areas, especially areas between patch and perforated forests;
- regularly monitor the dynamics and patterns of forest and overall land cover change;
- promote sustainable forest management practices with incentives to local people, e.g. agroforestry, or forest-based enterprises to diversify the high dependency on forest resources;
- support effective implementation of conservation and development initiatives like the KSLCDI in collaboration with local, national, and regional partners;
- promote ecotourism involving local people to diversify livelihoods, building on the sacred value for different religions; and
- promote alternative energy sources (such as solar energy or biogas) to reduce pressure on the forests for fuelwood.

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References

Adler, D., Yeritsyan, B., Wilkinson, K., Pinhasi, R., Bar-Oz, G., Nahapetyan, S., et al. (2009). The Hrazdan Gorge Palaeolithic project, 2008–2009. In *Paper presented at the Archaeology of Armenia in Regional Context, Proceedings of the International Conference Dedicated to the 50th Anniversary of the Institute of Archaeology and Ethnography Held on September*.

Alam, A., Rashid, S., Bhat, M. S., & Sheikh, A. H. (2011). Impact of land use/land cover dynamics on Himalayan wetland ecosystem. *Journal of Experimental Sciences*, *2*(3), 60–64.

Atkinson, P. M., & Tatnall, A. (1997). Introduction neural networks in remote sensing. *International Journal of Remote Sensing*, *18*(4), 699–709.

Baatz, M., Arini, N., Schäpe, A., Binnig, G., & Linssen, B. (2006). Object-oriented image analysis for high content screening: Detailed quantification of cells and sub cellular structures with the Cellenger software. *Cytometry, A*, *69*(7), 652–658.

Badola, R., Hussain, S. A., Mishra, B. K., Konthoujam, B., Thapliyal, S., & Dhakate, P. M. (2010). An assessment of ecosystem services of Corbett Tiger Reserve, India. *The Environmentalist*, *30*(4), 320–329.

Bajracharya, B., Uddin, K., Chettri, N., Shrestha, B., & Siddiqui, S. A. (2010). Understanding land cover change using a harmonized classification system in the Himalaya. *Mountain Research and Development*, *30*(2), 143–156. http://dx.doi.org/10.1659/MRD-JOURNAL-D-09-00044.1

Bawa, K. S., & Seidler, R. (2015). Deforestation and sustainable mixed-use landscapes: A view from the Eastern Himalaya. *Annals of the Missouri Botanical Garden*, *100*(3), 141–149.

Bharti, R. R., Adhikari, B. S., & Rawat, G. S. (2012). Assessing vegetation changes in timberline ecotone of Nanda Devi National Park, Uttarakhand. *International Journal of Applied Earth Observation and Geoinformation*, *18*, 472–479.

Biswas, S., & Khan, D. K. (2011). Habitat fragmentation and nutrient dynamics in tropical dry deciduous forests of West Bengal, India. *ARPN Journal of Science and Technology*, *2*(Special Issue), 109–119.

Brockman, N. C. (2011). . *Encyclopedia of Sacred Places* (vol. 2) ABC-CLIO.

Burkhard, B., Kroll, F., Muller, F., & Windhorst, W. (2009). Landscape's capacities to provide ecosystem services—A concept for land-cover based assessments. *Landscape Online*, *15*, 1–22.

Chettri, N., Uddin, K., Chaudhary, S., & Sharma, E. (2013). Linking spatio-temporal land cover change to biodiversity conservation in the Koshi Tappu Wildlife Reserve, Nepal. *Diversity*, *5*(2), 335–351.

Chettri, N., Sharma, E., & Zomer, R. (2012). Changing paradigm and post 2010 targets: Challenges and opportunities for biodiversity conservation in the Hindu Kush Himalayas. *Tropical Ecology*, *53*(3), 245–259.

Chettri, N., Sharma, E., & Thapa, R. (2009). Long term monitoring using transect and landscape approaches within Hindu Kush Himalayas. In E. Sharma (Ed.), *Proceedings of the International Mountain Biodiversity Conference International Mountain Biodiversity Conference Kathmandu* (pp. 201–208). Kathmandu, Nepal: ICIMOD.

Chettri, N., Shakya, B., Thapa, R., & Sharma, E. (2008). Status of protected area system in the Hindu Kush Himalaya: An analysis of PA coverage. *International Journal of Biodiversity Science and Management*, *4*(3), 164–178.

Chettri, N., Sharma, E., Shakya, B., & Bajracharya, B. (2007). Developing forested conservation corridors in the Kangchenjunga landscape, Eastern Himalaya. *Mountain Research and Development*, *27*(3), 211–214.

Chettri, N., Sharma, E., Deb, D., & Sundariyal, R. (2002). Impact of firewood extraction on tree structure, regeneration, and wood biomass productivity in a trekking corridor of the Sikkim Himalaya. *Mountain Research and Development*, *22*(2), A1–A3.

Crooks, K. R., Burdett, C. L., Theobald, D. M., Rondinini, C., & Boitani, L. (2011). Global patterns of fragmentation and connectivity of mammalian carnivore habitat. *Philosophical Transactions of the Royal Society B: Biological Sciences*, *366*(1578), 2642–2651.

De, A., & Tiwari, A. (2008). Estimation of patchiness: A measure of fragmentation in the Rajaji-Corbett National Park and adjoining areas, Uttarakand. *India. International Journal of Ecology and Environmental Sciences*, *34*(4), 345–349.

Eastman, J. R. (2009). *IDRISI Taiga guide to GIS and image processing*. Worcester (MA), USA: Clark Labs, Clark University.

Ellis, E. C., & Ramankutty, N. (2008). Putting people in the map: Anthropogenic biomes of the world. *Frontiers in Ecology and the Environment*, *6*(8), 439–447.

Fahrig, L. (2003). Effects of habitat fragmentation on biodiversity. *Annual Review of Ecology, Evolution, and Systematics*, *34*, 487–515.

Fenoglio, M. S., Srivastava, M. S., Valladares, D., Luciano, G., & Salvo, A. (2012). Forest fragmentation reduces parasitism via species loss at a multiple tropical level. *Journal of Ecology*, *93*, 2407–2420.

Frey, H., & Paul, F. (2012). On the suitability of the SRTM DEM and ASTER GDEM for the compilation of topographic parameters in glacier inventories. *International Journal of Applied Earth Observation and Geoinformation*, *18*, 480–490.

Fu, B. J., Zhao, W. W., Chen, L. D., Zhang, Q. J., Lü, Y. H., Gulinck, H., et al. (2005). Assessment of soil erosion at large watershed scale using RUSLE and GIS: A case study in the Loess Plateau of China. *Land Degradation & Development*, *16*(1), 73–85.

Gerlitz, J.-Y., Hunzai, K., & Hoermann, B. (2012). Mountain poverty in the Hindu-Kush Himalayas. *Revue canadienne d'études du développement*, *33*(2), 250–265.

Gilani, H., Shrestha, H. L., Murthy, M. S. R., Phuntso, P., Pradhan, S., Bajracharya, B., et al. (2015). Decadal land cover change dynamics in Bhutan. *Journal of Environmental Management*, *148*, 91–100.

Gregorio, A. D. (2005). *Land cover classification system classification concepts and user manual Software version (2)*. Rome: Food and Agriculture Organization of the United Nations.

Halada, L. (2010). *Ecosystem services of mountains: An urgent research area*. Brussels, Belgium: ALTERNet.

Hansen, M. C., Stehman, S. V., & Potapov, P. V. (2010). Quantification of global gross forest cover loss. *Proceedings of the National Academy of Sciences of the United States of America*, *107*(19), 8650–8655.

Hijmans, R. J., Cameron, S. E., Parra, J. L., Jones, P. G., & Jarvis, A. (2005). Very high resolution interpolated climate surfaces for global land areas. *International Journal of Climatology*, *25*(15), 1965–1978.

Hofer, T., & Messerli, B. (2006). Floods in Bangladesh: History, dynamics and rethinking the role of the Himalayas. *Ecology*, *29*, 254–283.

IPCC. (2007). *Climate change 2007—Impacts, adaptation and vulnerability*. Cambridge, MA: Intergovernmental Panel on Climate Change.

IPCC. (2014). *Climate change 2014: Impacts, adaptation, and vulnerability. Part A: Global and sectoral aspects. Contribution of working group II to the fifth assessment report of the intergovernmental panel on climate change*. Cambridge, United Kingdom and New York, NY, USA: Cambridge University Press.

Ives, J. D., & Messerli, B. (1989). *The Himalayan dilemma*. Great Britain: Routledge.

Kandel, K., Huettmann, F., Suwal, M. K., Regmi, G. R., Nijman, V., Nikaris, K. A. I., et al. (2015). Rapid multi-nation distribution assessment of a charismatic conservation species using open access ensemble model GIS predictions: Red panda (*Ailurus fulgens*) in the Hindu-Kush Himalaya region. *Biological Conservation*, *181*, 150–161.

Kettunen, M., Terry, A., Tucker, G., & Jones, A. (2007). Guidance on the maintenance of landscape connectivity features of major importance for wild flora and fauna. In *Guidance on the implementation of Article 3 of the Birds Directive (79/409/EEC) and Article 10 of the Habitats Directive (92/43/EEC)*. Brussels, Belgium: Institute for European Environmental Policy (IEEP).

Kintz, D. B., Young, K. R., & Crews-Meyer, K. A. (2006). Implications of land use/land cover change in the buffer zone of a national park in the tropical Andes. *Environmental Management*, *38*(2), 238–252.

Kubiszewski, I., Costanza, R., Dorji, L., Thoennes, P., & Tshering, K. (2013). An initial estimate of the value of ecosystem services in Bhutan. *Ecosystem Services*, *3*, e11–e21.

Kunwar, R. M., Mahat, L., Acharya, R. P., & Bussmann, R. W. (2013). Medicinal plants, traditional medicine, markets and management in far-west Nepal. *Journal of Ethnobiology and Ethnomedicine*, *9*, 24.

Lambin, E. F., Turner, B. L., Geist, H. J., Agbola, S. B., Angelsen, A., Bruce, J. W., et al. (2001). The causes of land-use and land-cover change: Moving beyond the myths. *Global Environmental Change*, *11*(4), 261–269.

Lang, S., Kääb, A., Pechstädt, J., Flügel, W.-A., Zeil, P., Lanz, E., et al. (2011). Assessing components of the natural environment of the Upper Danube and Upper Brahmaputra river basins. *Advances in Science and Research*, *7*(1), 21–36.

Lawler, J. J., Lewis, D. J., Nelson, E., Plantinga, A. J., Polasky, S., Whithey, J. C., et al. (2013). Projected land-use change impacts on ecosystem services in the United States. *Proceedings of the National Academy of Sciences of the United States of America*, *111*(20), 7492–7497. http://dx.doi.org/10.1073/pnas.1405557111

Leal, I. R., Filgueiras, B. K., Gomes, J. P., Iannuzzi, L., & Andersen, A. N. (2012). Effects of habitat fragmentation on ant richness and functional composition in Brazilian Atlantic forest. *Biodiversity and Conservation*, *21*(7), 1687–1701.

Lele, N., & Joshi, P. (2009). Analyzing deforestation rates, spatial forest cover changes and identifying critical areas of forest cover changes in North-East India during 1972–1999. *Environmental Monitoring and Assessment*, *156*(1–4), 159–170.

Lôbo, D., Leão, T., Melo, F. P., Santos, A. M., & Tabarelli, M. (2011). Forest fragmentation drives Atlantic forest of northeastern Brazil to biotic homogenization. *Diversity and Distributions*, *17*(2), 287–296.

Loveland, T., Reed, B., Brown, J., Ohlen, D., Zhu, Z., Yang, W. M. J., et al. (2000). Development of a global land cover characteristics database and IGBP DISCover from 1 km AVHRR data. *International Journal of Remote Sensing*, *21*(6–7), 1303–1330.

McGarigal, K., & Cushman, S. A. (2002). Comparative evaluation of experimental approaches to the study of habitat fragmentation effects. *Ecological Applications*, *12*(2), 335–345.

Millington, A. C., Velez-Liendo, X. M., & Bradley, A. V. (2003). Scale dependence in multitemporal mapping of forest fragmentation in Bolivia: Implications for explaining temporal trends in landscape ecology and applications to biodiversity conservation. *ISPRS Journal of Photogrammetry and Remote Sensing*, *57*(4), 289–299.

Mittermeier, R., Gils, P., Hoffman, M., Pilgrim, J., Brooks, T., Mittermeier, C. G., et al. (2004). *Hotspots revisited. Earth's biologically richest and most endangered terrestrial ecoregions*. Arlington, VA: Conservation International, CEMEX, USA.

Myers, N. (1986). The environmental dimension to security issues. *Environmentalist*, *6*(4), 251–257.

Nagabhatla, N., Finlayson, C. M., & Sellamuttu, S. S. (2012). Assessment and change analyses (1987–2002) for tropical wetland ecosystem using earth observation and socioeconomic data. *European Journal of Remote Sensing*, 215–232. http://dx.doi.org/10.5721/EuJRS20124520

Nagendra, H., Pareeth, S., Sharma, B., Schweik, C. M., & Adhikari, K. R. (2008). Forest fragmentation and regrowth in an institutional mosaic of community, government and private ownership in Nepal. *Landscape Ecology*, *23*(1), 41–54.

Nagendra, H., Paul, S., Pareeth, S., & Dutt, S. (2009). Landscapes of protection: Forest change and fragmentation in Northern West Bengal, India. *Environmental Management*, *44*(5), 853–864.

Oli, K. P., Chaudhary, S., & Sharma, U. R. (2013). Are governance and management effective within protected areas of the Kanchenjunga Landscape (Bhutan, India and Nepal)? *PARKS*, *19*(1), 1–12.

Olson, D. M., Dinerstein, E., Wikramanayake, E. D., Burgess, N. D., Powell, G. V., Underwood, E. C., et al. (2001). Terrestrial ecoregions of the world: A new map of life on earth a new global map of terrestrial ecoregions provides an innovative tool for conserving biodiversity. *Bioscience*, *51*(11), 933–938.

Pandit, M., Sodhi, N. S., Koh, L. P., Bhaskar, A., & Brook, B. W. (2007). Unreported yet massive deforestation driving loss of endemic biodiversity in Indian Himalaya. *Biodiversity and Conservation*, *16*(1), 153–163.

Pant, K. P., Rasul, G., Chettri, N., Rai, K. R., & Sharma, E. (2012). Value of forest ecosystem services: A quantitative estimation from the Kangchenjunga landscape in eastern Nepal. In *ICIMOD working paper (2012/5)*. Kathmandu, Nepal: ICIMOD.

Pardini, R., de Arruda Bueno, A., Gardner, T. A., Prado, P. I., & Metzger, J. P. (2010). Beyond the fragmentation threshold hypothesis: Regime shifts in biodiversity across fragmented landscapes. *PLoS ONE*, *5*(10), e13666.

Peres, C. A., Gardner, T. A., Barlow, J., Zuanon, J., Michalski, F., Lees, A. C., et al. (2010). Biodiversity conservation in human-modified Amazonian forest landscapes. *Biological Conservation*, *143*(10), 2314–2327. http://dx.doi.org/10.1016/j.biocon.2010.01.021

Reddy, C. S., Sreelekshmi, S., Jha, C. S., & Dadhwal, V. K. (2013). National assessment of forest fragmentation in India: Landscape indices as measures of the effects of fragmentation and forest cover change. *Ecological Engineering*, *60*, 453–464. http://dx.doi.org/10.1016/j.ecoleng.2013.09.064

Roy, R., Schmidt-Vogt, D., & Myrholt, O. (2009). "Humla Development Initiatives" for better livelihoods in the face of isolation and conflict. *Mountain Research and Development*, *29*(3), 211–219.

Saikia, A., Hazarika, R., & Sahariah, D. (2013). Land-use/land-cover change and fragmentation in the Nameri Tiger Reserve, India. *Geografisk Tidsskrift—Danish Journal of Geography*, *113*(1), 1–10.

Sala, O. E., Chapin, F. S., Armesto, J. J., Berlow, E., Bloomfield, J., Dirzo, R., et al. (2000). Global biodiversity scenarios for the year 2100. *Science*, *287*(5459), 1770–1774.

Saunders, D. A., Hobbs, R. J., & Margules, C. R. (1991). Biological consequences of ecosystem fragmentation: A review. *Conservation Biology*, *5*(1), 18–32.

Schild, A. (2008). ICIMOD's position on climate change and mountain systems: The case of the Hindu Kush-Himalayas. *Mountain Research and Development*, *28*(3), 328–331.

Schleuning, M., Farwig, N., Peters, M. K., Bergsdorf, T., & Bleher, B. (2011). Forest fragmentation and selective logging have inconsistent effects on multiple animal-mediated ecosystem processes in a tropical forest. *PLoS ONE*, *6*(11).

Sharma, E., Chettri, N., & Oli, K. P. (2010). Mountain biodiversity conservation and management: A paradigm shift in policies and practices in the Hindu Kush-Himalayas. *Ecological Research*, *25*(5), 909–923. http://dx.doi.org/10.1007/s11284-010-0747-6

Sharma, E., Chettri, N., Gurung, J., & Shakya, B. (2007). *Landscape approach in biodiversity conservation: A regional cooperation framework for implementation of the Convention on Biological Diversity in Kangchenjunga Landscape*. Kathmandu, Nepal: ICIMOD.

Singh, S. P., Singh, V., & Skutsch, M. (2010). Rapid warming in the Himalayas: Ecosystem responses and development options. *Climate and Development*, *2*(3), 221–232.

Solomon, S., Qin, D., Manning, M., Chen, Z., Marquis, M., Averyt, K. V., et al. (2007). IPCC, 2007: Climate change 2007: The physical science basis. In *Contribution of working group I to the fourth assessment report of the intergovernmental panel on climate change*. Cambridge: Cambridge University Press.

Stokes, D., & Morrison, P. (2003). GIS-based conservation planning: A powerful tool to be used with caution. . .. *Conservation in Practice*, *4*(1), 38–42.

Thuiller, W., Albert, C., Araújo, M. B., Berry, P. M., Cabeza, M., & Guisan, A. (2008). Predicting global change impacts on plant species' distributions: Future challenges. *Perspectives in Plant Ecology, Evolution and Systematics*, *9*(3), 137–152.

Turner, B., Meyer, W. B., & Skole, D. L. (1994). Global land-use/land-cover change: Towards an integrated study. *AMBIO*, *23*, 91.

Uddin, K., Shrestha, H. L., Murthy, M., Bajracharya, B., Shrestha, B., Gilani, H., et al. (2015). Development of 2010 national land cover database for the Nepal. *Journal of Environmental Management*, *148*, 82–90.

Vadrevu, K. P., Justice, C., Prasad, T., Prasad, N., & Gutman, G. (2015). Land cover/land use change and impacts on environment in South Asia. *Journal of Environmental Management*, *148*, 1–3.

Vogt, P., Riitters, K. H., Estreguil, C., Kozak, J., Wade, T. G., & Wickham, J. D. (2007). Mapping spatial patterns with morphological image processing. *Landscape Ecology*, *22*(2), 171–177.

Wenguang, Z., Yuanman, H., Jinchu, H., Yu, C., Jing, Z., & Miao, L. (2008). Impacts of land-use change on mammal diversity in the upper reaches of Minjiang River, China: Implications for biodiversity conservation planning. *Landscape and Urban Planning*, *85*(3), 195–204.

Zomer, R., & Oli, K. P. (2011). *Kailash sacred landscape conservation initiative—Feasibility assessment report*. Kathmandu: ICIMOD.