Tracking Forest Loss and Fragmentation During 1930–2020 in Asian Elephant (*Elephas Maximus*) Habitats in Nepal

Ashok Kumar Ram (✉ elephas.maximus@yahoo.com)

Ministry of Forests and Environment

Nabin Kumar Yadav

Ministry of Industry, Tourism, Forests and Environment, Province 2, Janakpur

Pem Narayan Kandel

Ministry of Forests and Environment

Samrat Mondol

Wildlife Institute of India (WII)

Bivash Pandav

Wildlife Institute of India (WII)

Lakshminarayanan Natarajan

Wildlife Institute of India (WII)

Naresh Subedi

National Trust for Nature Conservation (NTNC)

Dipanjan Naha

University of Georgia

C. Sudhakar Reddy

National Remote Sensing Centre, Indian Space Research Organisation

Babu Ram Lamichhane

National Trust for Nature Conservation (NTNC)

Research Article

Keywords: Elephant, deforestation, habitat loss, fragmentation, conflict

Posted Date: July 22nd, 2021

DOI: <https://doi.org/10.21203/rs.3.rs-717308/v1>

License: © ⓘ This work is licensed under a Creative Commons Attribution 4.0 International License. [Read Full License](#)

Abstract

Forest cover is the primary determinant of elephant distribution, thus, understanding forest loss and fragmentation is crucial for elephant conservation. We assessed deforestation and patterns of forest fragmentation during 1930–2020 in Chure Terai Madhesh Landscape (CTML) which covers the entire elephant range in Nepal. Forest cover maps and fragmentation matrices were generated using multi-source data (Topographic maps and Landsat images of 1930, 1975, 2000, and 2020) and spatiotemporal changes were quantified. Forest cover within the elephant range was 19,069 km². Overall, 21.5% of elephant habitat was lost between 1930 to 2020, with a larger (12.3%) forest cover loss between 1930 & 1975. Area of the large forests (Core 3) in CTML has decreased by 43.08% whereas smaller patches (Core 2, Core 1, edge and patch forests) has increased multifold during 1930–2020. The continued habitat loss and fragmentation probably fragmented elephant populations during the last century and made them insular with long-term ramifications for elephant conservation and human-elephant conflict. Given the substantial loss in forest cover and high levels of fragmentation, improving the resilience of elephant habitats in Nepal would urgently require habitat and corridor restoration to enable the movement of elephants.

Introduction

Deforestation and conversion of natural areas into human use impacts the Earth's ecosystems and functions and threatens biodiversity^{1,2}. The population of many wildlife species are declining globally, and about a million species are under threat of extinction primarily due to habitat loss/degradation, overexploitation, climate change, illegal wildlife trade, direct persecution, and conflict with humans^{3–5}. Fragmentation is a significant factor leading to the loss of biodiversity in forested landscapes⁶. Habitat fragmentation affects ecological patterns and processes by increasing the number of forest patches, reducing the patch size, interrupting connectivity within the ecological network^{7–9}, and impacting several species¹⁰. Habitat fragmentation could alter animal communities and trigger cascading effects on plants and ecosystem functions, including their carbon storage potential^{11–13}. Continued fragmentation can lead to microclimatic changes in the edges, reduced core habitat, and eases the establishment of invasive species towards the forest interiors^{14,15}.

Wide-ranging large mammals are more vulnerable to extinction because of their needs for large and intact habitats¹⁶. Elephants are the largest living terrestrial mammals facing typical threats¹⁷. The rise in human population and expansion of agriculture had led to habitat loss and fragmentation, resulting in a significant decline in elephant populations across Asia and Africa^{18–20}. Asian elephants are confined to 5% of the historic elephant range²⁰. Elephants use large areas to meet their dietary and reproductive requirements^{21,22}. Their home range size varies according to the forage availability and nature of the habitat^{23–25}. With reduced connectivity, loss of habitats, and a rise in anthropogenic impacts, elephants are forced to come near settlements, resulting in frequent conflict with humans, ranging from crop damage to direct persecution^{17,26}.

Nepal is one of the elephant range countries, with an estimated 200 elephants that occur for the most part^{27,28}. The Chure Terai Madhesh Landscape (CTML) encompasses the entire elephant habitat in Nepal^{29,30}. Before the 1950s, the forest of CTML was reasonably intact³¹ and had a wide distribution of elephants that reportedly occurred in high densities^{32–34}. A large tract of forests was converted into agriculture between 1950 and 1970, and wildlife was hunted down as agricultural pests with no legal protection at all³⁵. Several hundred wild elephants were also captured (287 between 1800 and 1975) and moved to captivity³³. Deforestation led to the further decline of the elephant population.

In the CTML, the elephant ranges run east-west along the foothills of the Himalayas²⁹. Protected areas (national parks and wildlife reserves) and forests outside the protected network constitute significant elephant habitats in CTML. The landscape includes both government and community-managed forests. Different landscape-level conservation approaches, including the Terai Arc Landscape (TAL) program, were implemented for biodiversity conservation in the CTML region³⁶. As a result, CTML is a biodiversity hotspot and experienced significant habitat loss and fragmentation, causing human-elephant conflict (HEC)³⁷.

Despite increasing threats, landscape-specific information on the change in forest cover and habitat fragmentation is lacking for CTML and is urgently required for effective conservation planning for elephants. This study quantifies the change in forest cover for the last 90 years using high-resolution imagery, estimating forest loss and habitat fragmentation in the CTML. We use the findings to relate habitat loss, fragmentation, and trends in HEC and discuss implications for elephant conservation in the human-dominated landscapes of Nepal and elsewhere. The findings will have implications for devising actionable strategies for elephant conservation and protecting existing forested habitats within human-dominated landscapes in Nepal.

Methods And Materials

Study area

Chure-Terai-Madhesh landscape (CTML) covers the entire elephant distribution range in Nepal. The CTML spreads across 25 districts and covers an area of 42,456 km² (Fig. 1). CTML comprises five physiographic units i.e., Chure hills (34.4%); Chure narrow gorges (2.2%); Dun/Inner Terai (8.4%); Bhavar region (14.9%); and Terai Madhesh (40%). Forty-eight percent of the landscape comprises agriculture and settlement; 47.16% forest, shrub-land, and grassland; and the rest 4.65% river and riverbed³⁸. CTML is a part of the global biodiversity hotspot³⁹ and provides essential environmental services such as groundwater recharge for more than half of Nepal's human population (~ 15 million)^{40,41}. The major habitat types are Himalayan subtropical broadleaved forests, b. Gangetic plains and moist deciduous forest, and c. Terai-Duar savannas and grassland. Apart from elephants, the study area is also a refuge for several endangered large mammals, including the tiger (*Panthera tigris*), greater one-horned rhinoceros (*Rhinoceros unicornis*), Gaur (*Bos gaurus*), and wild buffalo (*Bubalus bubalis arnee*). The annual rainfall ranges between 1,138 mm to 2,680 mm, with over 80% of the rain occurring during monsoon months⁴². The altitudinal range lies between 60–1500 meters⁴³. CTML is densely populated with an average human density of 392 persons/km²⁴⁰. Sixty percent of the

people depend on subsistence agriculture and are involved in farm and off-farm-based livelihood activities (Chaudhary and Subedi, 2019). Paddy (*Oryza sativa*), maize (*Zea mays*), wheat (*Triticum aestivum*), lentils (*Lens culinaris*) are some major food crops, where jackfruit (*Artocarpus heterophyllus*), mangoes (*Mangifera indica*), bananas (*Musa acuminata*) are some fruit crops farmed in the area ⁴⁴. Large-scale linear infrastructure projects and mining activities are the major drivers of deforestation and habitat fragmentation in the landscape.

We divided CTML into four regions (Eastern, Central, Western and Far-western) of similar size to assess the extent of forest loss (Table 1). Thus, elephants are distributed in four population clusters with limited connectivity viz. eastern population (Mechi River to Kamala River), (b) a central population (Kamala River to Narayani River), (c) western population (Narayani River to Western boundary of Dang district), and (d) a far-western population (Eastern boundary of Banke district to Mahakali River) ^{45,46}.

Table 1
Four different regions within Chure Terai Madhesh Landscape Nepal, area, forest cover and elephant population status. The elephant population was obtained from Ram & Acharya (2020).

SN	Region	Coverage (Districts)	Total Area (Km ²)	% Forest cover	Elephant population
1	Eastern	Jhapa to Siraha	11,116.96	31.92	Residential: 27–35; ~100 migratory elephants each year from West Bengal, eastern India).
2	Central	Dhanusa to Chitwan	8,169.43	46.17	Residential: 45–53
3	Western	Nawalparasi to Dang	8,777.95	56.89	Migratory: 8–12
4	Far-Western	Banke to Kanchanpur	14,391.54	46.94	Residential: 80–125; ~45 migratory (from Uttarakhand and Uttar Pradesh, India migrated to far western habitats in Nepal)
Total			42,455.88	44.92	

Derivation of forest cover

We analyzed forest cover change and fragmentation using both the patch and landscape metrics and considered forest fragmentation as habitat fragmentation ⁴⁷. We categorized forested areas as natural and plantations with a tree canopy cover of more than 10 percent and an area of more than 0.5 ha ⁴⁸. We used the hybrid classification techniques to combine high-resolution images, medium resolution images, and digitization of topographic maps. First of all, we prepared a forest cover map of the 1930s by digitizing greenwash areas shown on topographical maps prepared by Army Map Service, U.S. Army, Washington, surveyed during 1920–1940 (<http://legacy.lib.utexas.edu/maps/ams/india/>) at 1:250,000 scale. Due to the unavailability of multi-spectral satellite images of the study area before the 1970s, we relied on the existing topographic maps to obtain forest cover of 1930 ^{49,50}

^{51,52} found 5–10% inherent errors at various stages of land cover change analysis; while using historical data and topographic maps. The inaccuracy of forest cover mapping was minimized by visual interpretation and overlay analysis in the topographic maps. In addition, we resampled all the digital images at a 30-meter resolution to improve the mapping errors. ^{51,52} reported the reliability of topographical maps to reconstruct forest cover. We also obtained the forest cover map of 1975 by on-screen digitization of Landsat 1 TM level 1 satellite images.

We produced the forest cover maps of 2000 and 2020 from Landsat imagery scenes of respective years (Table 2; Figure. 2). All the Landsat data processing was conducted using the cloud-computing technology in the Google Earth Engine (GEE) platform (<https://earthengine.google.org/>). The GEE platform carried out a fast analysis using Google's computing infrastructure ^{53,54}. We used the pre-processed Landsat imagery available through GEE to assess forest cover change across the study area ⁵⁵.

Table 2
Sources of data used in this study.

SN	Data layer	Source	Spatial resolution (m)	Year
1	Topographic map	Army Map Service, U.S. Army, Washington	Scale 1:250,000 m (based on Arial photo)	1920–1940
2	Landsat 1 TM	Earth Explorer (USGS)	60 m	1975–1976
3	Landsat 5 Surface Reflectance Tier 1	GEE dataset (USGS)	30 m	2000
4	Landsat 8 Surface Reflectance GEE dataset	GEE dataset (USGS)	30 m	2020
5	Administrative boundary	Department of Survey, Nepal	Scale 1:25,000 (Based on Arial photo)	1996–1998

We used a cloud screening algorithm to remove cloud contaminated pixels from each Landsat image by applying quality assessment (QA) bands for 2000 and 2020. Then, we produced an annual composite by taking the median value from images from the target year ⁵⁶. We delineated > 1000 reference points for each period 2000 and 2020 respectively. We used supervised machine learning classifiers, i.e., Random Forest (RF), to classify remotely sensed data ⁵⁷.

Random Forest Classifier creates a set of decision trees from a randomly selected subset of the training set and aggregates the votes from different decision trees to classify the image ⁵⁸. The classified image was downloaded as raster tiff files. The raster was converted into vector polygons and overlaid with high-resolution google earth images of respective years. The final forest cover map was obtained with the highest accuracy by post-processing (validating) the forest polygons through onscreen digitization to match the forests visible in Google images ⁵⁷

Data analysis

Analysis of forest loss/gain

Forest cover maps of the four different periods of 1930 (before malaria eradication), 1975 (the initial stage of PA system development), 2000 (well-established PA system) & 2020 (current scenario) were post-processed according to FAO forest definition. These layers were analyzed to understand changes in extent and location of forests using a post-classification change detection technique in Arc GIS 10.4.

We have estimated the conversion of forests into the non-forest area on a grid overly basis and grids were generated on the basis of minimum home range size of elephants i.e., 18 km² ^{45,59}. We generated 5× 5 km² grids for the time series assessment and analyzed spatial distribution trends of forest cover in these grids from 1930–1975, 1975–2000, and 2000–2020 ^{49,60}. We computed the forest cover area (distribution of transitions and persistence of forest) of four different periods in each grid using the zonal statistics tool of ArcGIS software ⁶¹. Overall, forest cover change was calculated by combining all the grids and calculating the annual deforestation rate (percentage) using a compound-interest-rate formula ⁶².

$$r = \frac{1}{t_2-t_1} \times \ln \frac{a_2}{a_1},$$

where a1 and a2 are the area covered by forest at times t1 and t2. The region wise rate of deforestation was computed and presented.

Modeling Forest fragmentation

We carried out habitat fragmentation analysis in the four regions of CTML (Fig. 1) and measured fragmentation in terms of core, perforated, edge, and patches. We used 30 m cell resolution for fragmentation analysis for four different periods. We used patch analyst ⁶³ to obtain the patch matrix for each region viz. patch density and size (number of patches, mean patch sizes, patch size standard deviation), edge metrics (edge density, mean patch edge), and shape index (mean shape Index, mean perimeter area ratio, mean patch fractal dimension), (Supplementary table S1).

Similarly, Landscape Fragmentation Tool (LFT V2.0, <http://clear.uconn.edu/tools/lft/lft2/>) was used to estimate landscape metrics ⁶⁴. The change of fragmentation during the 1930 to 2020 periods was carried out by cross-tabulating the fragmentation classes. Landscape Fragmentation Tool (LFT) classifies forests at pixel-level into fragmentation classes: core 1, core 2, core 3, perforated, edge, and patch. Core forests are located far from the forest/non-forest boundary and surrounded by other forest areas. We considered the core forest as 100 m distance from the edge ⁶⁵. The core forests include three different types – 1) Core1: forest patches area < 250 acres (1.012km²), 2) Core 2: Medium core (forest patches area between 250–500 acres (1.01–2.2 km²), and Core 3: large core (Forest patches area > 500 acres (> 2.2 km²) ⁴⁹. The peripheral forest was further classified into perforated (i) inner edge: forest pixels on the edge of small interior non-forest, and (ii) edge forest or outer edge: pixels that are between forest and large non-forest areas ⁶⁶.

Results

Temporal change of forest cover in CTML

We estimated 24,315 km² of forest cover in 1930. The forest cover was reduced to 19,069 km² in 2020, with an annual rate of 0.27%. The deforestation rate (0.29%) was higher between 1930 and 1975. The highest rate of deforestation was documented in western region (0.33%) followed by eastern (0.29%), far western (0.28%) and central (0.16%) region between 1930 to 2020 (Table 3). In 2020, the far western region had the highest forest area (35.42%), followed by the western region (26.18%), central (19.78%), and eastern region (18.61%) of CTML (Table 3)

Table 3
Status of forest cover by area in 1930, 1975, 2000 and 2020 in Chure Terai Madhesh Landscape (CTML), Nepal. The total forest change percentage and annual rate of forest change (in parenthesis) is presented for four different time periods.

Region	Forest Area in different years (km ²)				Percentage forest change (annual rate of forest change)			
	1930	1975	2000	2020	1930–1975	1975–2000	2000–2020	1930–2020
Eastern	4,607.92	4,084.94	3,781.68	3,548.48	-11.35 (-0.27)	-7.42 (-0.31)	6.57 (-0.32)	22.99 (-0.29)
Central	4,336.84	4,162.02	3,917.77	3,771.95	4.03 (-0.09)	5.87 (-0.24)	3.87 (-0.19)	13.03 (-0.16)
Western	6,703.66	5,590.97	5,186.52	4,993.85	16.60 (-0.40)	7.23 (-0.30)	3.86 (-0.19)	25.51 (-0.33)
Far western	8,667.14	7,482.98	7,167.34	6,754.86	13.66 (-0.33)	4.22 (-0.17)	6.11 (-0.30)	22.06 (-0.28)
Total	24,315.56	21,320.92	20,053.32	19,069.14	12.32 (-0.29)	5.95 (-0.25)	5.16 (-0.25)	21.58 (-0.27)

(Table 3)

Spatial change in forest cover

Altogether 1,592 grids of 5 x 5 km² were used to analyze the spatial patterns of forest cover change. Deforestation was documented in most of the grids (n = 1505), and 75 grids lost entire forest area between 1930–2020. Increase in forest cover was observed in only 51 grids during the same period. The massive reduction in large forest patches (< 20 Km²) was documented for 26 grids (Fig. 3a, b, c), (Supplementary table S2, Supplementary figure S5)

Figure 3: Forest cover change in the Asian elephant habitat (the Chure Terai Madhesh Landscape), Nepal during the time periods a) 1930–1975, b) 1975–2000, 2000–2020.

(Fig. 3)

We calculated historical forest fragmentation for the last nine decades (1930–2020) and found that the total number of patches increased from 201 in 1930 to 28,559 in 2020. However, the highest decrease in mean patch size (121 km² in 1930 decreased to 0.7 km² in 2020) indicates that the forest has been fragmented into small patches. The mean perimeter ratio of the forest has been increased from 187 in 1930 to 1210 in 2020. The edge metrics showed that edge density increased from 548 (m/km²) to 3630 (m/km²), reduced mean patch edge to 2,426.63 ha from 66,271.31 ha. Similarly, the shape index suggested that the mean shape index (MSI) was decreased sharply where the mean perimeter area ratio (MPAR) increased progressively (Table 4).

Table 4
Forest fragmentation status in the CTML, Nepal in different time periods.

SN	Landscape metrics	1930	1975	2000	2020
1	Patch density and size				
a	Nump –No of patches	201	22,602	26,727	28,559
b	MPS – Mean Patch size (km ²)	121	0.9	0.8	0.7
c	PSSD – Patch size standard deviation	64,458.3	4,643.1	3,762.5	3,187.2
2	Edge metrics				
d	ED- Edge density (m/ km ²)	548	2849	3263	3630
e	MPE-Mean patch edge	66,271.3	2,691.4	2,451.4	2,426.6
3	Shape Index				
f	MSI-Mean shape index	1.8	1.4	1.4	1.4
g	MPAR-Mean perimeter area ratio	187.4	1,274.4	1,245.5	1,210.8
h	MPFD-Mean patch fractal dimension	1.3	1.4	1.4	1.4

(Table 4)

Between 1930 and 2020, 21.58% of the forest area was converted to another land use category. The fragmentation analysis showed that the core forest (Core 3) size decreased by 43.08%, where core 2 and core 1 size increased severely by 320.86% and 1107.33%. The patch area increased from 0.16 km² to 210.70 km² between 1930 to 2020. The edge area increased from 1,086.54 km² to 3269.72 km², and the entire large core forests area (Core3) reduced significantly by 9,968.68 km² in 2020 (Table 5).

Table 5
Temporal Forest fragmentation (area in km²).

Fragmentation class	1930	1975	2000	2020	Change 1930–1975	% Change (1930–1975)	Change 1975–2000	% Change (1975–2000)	Change 2000–2020	% Change (2000–2020)	Change 1930–2020	% Change (1930–2020)
Patch	0.16	157.11	165.69	210.85	156.95	*	8.58	5.46	45.16	27.26	210.7	*
Edge	1086.55	2825.61	2910.84	3279.62	1739.06	160.05	85.23	3.02	368.78	12.67	2193.07	201.8
Perforated	0.67	1876.53	1430.23	1693.21	1875.86	*	-446.3	-23.78	262.97	18.39	1692.54	*
Core1	42.18	422.32	474.32	509.25	380.14	901.23	52	12.31	34.93	7.36	467.07	1107.
Core2	49.34	157.51	182.84	207.65	108.17	219.23	25.34	16.08	24.81	13.57	158.31	320.8
Core3	23136.67	15881.84	14889.4	13168.56	-7254.83	-31.36	-992.44	-6.25	-1720.84	-11.56	-9968.11	-43.08
Total	24315.56	21320.92	20053.32	19069.14	-2994.64	-12.32	-1267.6	-5.95	-984.19	-4.91	-5246.42	-21.58
* The estimate is not reliable as forest cover within these categories were very small in 1930.												

The Eastern region lost 22.99% of forest between 1930 and 2020. The core 3 decreased by 57.34%, whereas core 1 and core 2 increased simultaneously by 1019.26% and 409.08%. Similarly, the edge area increased by 219.91%. The central region lost 22.06% of the forest between 1930–2020. Core 3 decreased by 46.36%, whereas core1 and core 2 increased by 4254% and 648%. The western region lost 13.03% of the forest, and core 3 forests were reduced by 30.88%,

whereas core 1 and core 2 increased by 488% and 162%. Finally, the far western region lost 5.51% of the forest, and the core 3 forest was reduced by 37.11%, whereas core 1 and core 2 increased by 663% and 145% simultaneously.

The overall forest fragmentation result suggests that the highest fragmentation occurred in the eastern region (in core 3), followed by the central, far western, and western region, where the core forest (core 3) was reduced by 57.34%, 46.36%, 37.11%, and 30.88% simultaneously (Table 5 and Table 6), (Fig. 4; Supplementary figure S5).

Table 6
Region wise forest fragmentation in Nepal.

Fragmentation class (Area in km ²)	Eastern					Central					Western	
	1930	1975	2000	2020	1930–2020 %change	1930	1975	2000	2020	1930–2020 %change	1930	19
Patch	0.01	69.68	333.42	93.36	-933500.00	0.14	49.51	224.21	75.1	-53542.86	0.000	22
Edge	297.17	863.34	1820.37	950.68	-219.91	322.23	1011.77	2802.83	1252.36	-288.65	219.920	46
Perforated	0.11	457.76	1360.58	423.75	-385127.27	0.11	826.08	3304.97	706.05	-641763.64	0.240	26
Core1	15.89	162.51	8.48	177.85	-1019.26	4.28	133.75	22.79	186.38	-4254.67	13.200	59
Core2	15.2	65.74	6.7	77.38	-409.08	8.83	40.92	18.22	66.08	-648.36	9.990	22
Core3	4279.55	2465.92	252.14	1825.46	57.34	8331.55	5420.95	794.33	4468.89	46.36	4093.490	33
Total	4607.92	4084.94	3781.68	3548.48	22.99	8667.14	7482.98	7167.34	6754.86	22.06	4336.840	41

Discussion

Patterns of forest cover change and fragmentation

Our study provides comprehensive information on forest cover (habitat) change and fragmentation within the primary elephant habitat in Nepal between 1930 and 2020. We documented the loss of more than one-fifth of the forest area and extensive fragmentation during this period. Our results suggest that the elephant habitat remained intact during the 1930s. However, the rate of deforestation was higher between 1930 and 1975 due to the conversion of forests into agricultural land. Forest cover loss was the highest in the western region, where the elephant population is the lowest. The regions with higher coverage of protected areas (central and far-western parts) had a comparatively lower rate of deforestation. Protected areas establishment (~ 6,000 km²) and restoration through community-based conservation programs (~ 300 km²) may have contributed to reducing deforestation rates after 1975 in CTML ⁴².

A previous study from south Asia documented a 29.62% forest cover loss between 1930 and 2014 with a 0.68% annual rate of deforestation ⁶⁷. The forest loss and rate of deforestation in CTML are lower than the average for South Asia ^{14,67, 68} also documented the annual rate of deforestation 0.49% for Nepal, which is higher than our results. Forests occupied 42.73 % of CTML in 2020, but forest cover was not evenly distributed throughout the landscape. A large part of the remaining forest occurs in the Chure region (> 70% forested), where the rate of deforestation was comparatively lower (0.18%/year between 1995 and 2010)) ^{42,69}. However, most of the flat and productive land of the CTML was converted into agricultural land with a higher rate of deforestation (i.e., 0.40%/year) between 1991 & 2010 ⁴². Among the four regions, the western part experienced the highest loss of forest cover (25.51%). The remaining forest cover (56%) and rate of deforestation (0.33) were found higher in the western region, where almost the entire forests lie outside of the protected areas. Despite massive forest clearance in Chitwan valley ⁷⁰ and other areas of central CTML, the rate of forest loss was only 0.16% per year. The establishment of Chitwan and Parsa National Parks and the intact forest remaining in the northern part of Bara and Rautahat may have contributed to lower deforestation rates in Central CTML CTML ⁷¹. The results indicate that Government should prioritize conservation efforts to restore elephants' movement within the human-dominated landscapes outside protected areas.

Forest fragmentation results suggested that large forest patches have decreased rapidly, whereas forests in the medium and small core have increased massively. Similarly, the area of forests in the patch, perforated, and edge category has also increased during the last nine decades (1930–2020), which indicated the high rate of forest fragmentation in the CTML. Landscape metrics analysis also reveals the massive fragmentation of forests between 1930 and 2020, increasing the patch number and decreasing patch size (Table 5,6 and Fig. 4) ⁶⁸. Similar to Nepal, a massive decline in extensive core forests and increase in fragmented patches has been documented in other elephant range countries India, Myanmar, Bangladesh, and Sri Lanka ^{60,62,72,73}. Fragmented forest patches should be connected through a combination of the week- and high-quality habitat to enable elephant connectivity throughout the landscape. The human pressure (illegal grazing, resources extraction) and risks of invasive species (*Lantana camera*, *Chromolaena odorata*, *Parthenium hysterophorus*, *Mikania micrantha*, etc.) spread are high in smaller and perforated forest patches as well as forest edges ⁷⁴.

Elephant habitat is more fragmented outside protected areas due to the high pressure of encroachment and developmental activities ⁷⁵. These forests are also used more frequently by the local communities to meet their subsistence needs of livestock grazing and dependence on forest products ^{76,77}. With increasing forest fragmentation, the elephants and other wildlife are also forced to live in smaller forest patches with spatial overlap with human activities ⁷⁸. This situation increases the chances of confrontation between humans and elephants, often leading to fatal attacks ^{30,79}. The eastern region had the highest forest

fragmentation (57.3% of large core forest lost) within our study, where HEC incidents were also the highest (DNPWC 2020). The eastern region also bears a long migratory route of a large herd of elephants (> 100) and provides habitat for some residential elephants. Although the forest cover is not significant within Koshitappu Wildlife Reserve (KTWR), it still provides refugia and a corridor for elephants in the eastern region. While navigating through the highly fragmented forests, there is always a threat of elephants getting deflected due to haphazard drives and another form of human resistance resulting in elephants ending up in human-use areas off the forests, as corroborated by telemetry studies on elephants in the landscape.

Drivers of deforestation and fragmentation

Several studies indicate loss of elephant habitats and fragmentation due to a combination of multiple factors such as (i.e., agriculture and settlement expansion, encroachments, irrigation, infrastructure development hydropower projects, illegal logging, mining, commercial plantations)^{60,80–82}. Additionally, expansion of oil palm plantation in Indonesia⁸³ and tea, paddy cultivation in north-east India has also contributed to habitat loss⁸⁴. However, in Nepal, forest conversion into farmlands through government policy was responsible for forest loss and fragmentation in the initial years (1930–1975), whereas encroachment and infrastructure development activities have continued the fragmentation at present and recent past and expansion of agriculture is a significant factor for conversion of elephant habitat in Nepal

A large part of the forest was lost or fragmented in CTML during the first 45 years (1930–1975). During this period, various socio-political changes and national policy of promoting forest conversion into agricultural land in Terai have contributed to such massive fragmentation of the forests in CTML³⁵. Three significant changes were a) fall of Rana regime and political instability, b) Private forests nationalization act 1957 and its impacts c) Land resettlement policy. Rana rulers used to grant forest and other lands as 'Birta' (grant their families and close relatives as private property) and provide to government employees and other servicemen to use a share of a product as a 'Jagir.' As a result, the tiny forest remained under government control⁸⁵. After the fall of the Rana Regime in 1951, a state of political instability in the country caused massive deforestation and wildlife hunting⁸⁶. In the meantime, the government of Nepal nationalized all the private forests by promulgating the "Private Forest nationalization Act, 1957"⁸⁷. As a result, owners of the private forests converted their forested land into farmlands to secure their land tenure^{88,89}. Similarly, eradicating malaria in CTML during the 1950s and introducing a new settlement policy by the government promoted thousands of hill migrants to convert Terai forests into farmlands⁷⁰. The human population in the CTML also increased many folds during this period, accelerating deforestation and forest degradation⁹⁰.

The deforestation rate was slightly low during 1975–2020. The primary reasons were a) establishment of protected area network, b) initiation of community participation in forest management c) well-established institutional setup for forest protection and management⁸⁵. With decreasing deforestation and increasing forests and wildlife conservation efforts, wildlife populations, including the elephants, have also increased (~ 50 individuals in the 1970s to > 200 in 2020; Shrestha et al. 1985; Ram & Acharya, 2020). However, the forest fragmentation continues in large parts of the forests outside of the protected areas. Large-ranging species like elephants are affected by this as they come into frequent clash with humans while navigating seasonally through these highly fragmented forests in CTML.

This study indicates that the conservation of large-ranging species like elephants and tigers in CTML has been challenging as most of the remaining forests are highly fragmented, especially outside the protected areas. With planned and ongoing infrastructure development activities in CTML, forest fragmentation continues to increase. It shows the importance of the landscape-level conservation approach and helps policymakers restore corridor and connectivity by the implementing metapopulation management of large mammals in Nepal and around the Globe.

Conclusion

Forest loss and fragmentation induced a severe threat to elephant conservation in Nepal. Such fragmentation brought both the elephants and humans along the forest's edge, where they interact with each other, often resulting in severe human-elephant conflict (HEC). Increasing the number of forest patches also increases the transparency in the migratory routes, increasing the poaching threats. Our research findings have implications for devising appropriate policies for conserving large mammals and their habitats in human-dominated landscapes in Nepal and beyond. Further understanding of the relationship between forest loss/fragmentation and human-elephant conflict is necessary. The particular focus of elephant conservation is necessary outside the protected areas and migration corridors where habitat is highly fragmented.

Declarations

Acknowledgements

We are thankful to Wildlife Institute of India (WII) Dehradun, Ministry of Forests and Environment (MOFE) Nepal, Department of National Parks and Wildlife Conservation (DNPWC), National Trust for Nature Conservation (NTNC), and Zoological Society of London (ZSL) Nepal office for support at different stages of the study. Dr. Hem Sagar Baral and Abdhesh Singh reviewed and provided crucial feedback on the earlier version of the manuscript. We acknowledge the contribution of Ms. Binita Khanal, field assistants Mr. Suman Acharya, Mr. Dinesh Ghimire, Mr. Badri Chaudhary, Mr. Anish Timsina, Ram Sahi, and Shankar Luitel. We are indebted to the support of the Director-General of DNPWC, National Park/Wildlife Reserve wardens, and Divisional Forest Officers of the Terai region during this study. The study would not be possible without the Rufford Small Grants Foundation (RSG), International Elephant Foundation (IEF), NTNC, and ZSL Nepal. Finally, we like to thank anonymous reviewers and editors for their constructive comments to improve the manuscript.

Research Ethics statement

We obtained research permission from the Department of National Parks and Wildlife Conservation Nepal (Ref no: 3066/073/74; June 02, 2017). We didn't carry out any experiments with live animals. We only carry out stakeholder consultation and questionnaire surveys by verbal consent from the participants for

the ground verifications.

Data accessibility

Upon publication of the article, all the supporting data for obtaining the results will be made available via the online data services such as dryad.

Author contributions

AKR, NS, SM, PNK & BP designed the study; AKR conducted the fieldwork; AKR, NKY BRL, & BP analyzed the data; AKR, BRL, NKY, SM, PNK & NS wrote the first draft of the manuscript; DN, PNK, CSR, LN and, all authors revised the manuscript.

References

1. Lambin, E. F. *et al.* The causes of land-use and land-cover change: Moving beyond the myths. *Glob. Environ. Chang.* **11**, 261–269 (2001).
2. Lawler, J. J. *et al.* Projected land-use change impacts on ecosystem services in the United States. *Proc. Natl. Acad. Sci. U. S. A.* **111**, 7492–7497(2014).
3. Bongaarts, J. *IPBES, 2019. Summary for policymakers of the global assessment report on biodiversity and ecosystem services of the Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services. Population and Development Review* vol. 45 (2019).
4. Pardini, R. O. B. S. O. L. E. T. E. Fragmentation and habitat loss. *Ref. Modul. Earth Syst. Environ. Sci.* 0–11 <https://doi.org/10.1016/b978-0-12-409548-9.09824-9> (2018).
5. Anthony, B. & Wasambo, J. Human-Wildlife Conflict Study Report. *Human-Wildlife Confl. Study Report*.55 (2009).
6. Fahrig, L. Effects of Habitat Fragmentation on Biodiversity. *Annu. Rev. Ecol. Evol. Syst.* **34**, 487–515 (2003).
7. Collinge, S. K. Ecological consequences of habitat fragmentation: Implications for landscape architecture and planning. *Landsc. Urban Plan*, **36**, 59–77 (1996).
8. Pierri-Daunt, A. B. & Tanaka, M. O. Assessing habitat fragmentation on marine epifaunal macroinvertebrate communities: An experimental approach. *Landsc. Ecol*, **29**, 17–28 (2014).
9. Fahrig, L. *et al.* Is habitat fragmentation bad for biodiversity? *Biol. Conserv.* **230**, 179–186 (2019).
10. Bustamante, R. O., Serey, I. A. & Pickett, S. T. A. Forest Fragmentation, Plant Regeneration and Invasion Processes Across Edges in Central Chile, In: Bradshaw G.A., Marquet P.A. (eds) *How Landscapes Change. Ecological Studies (Analysis and Synthesis)*. in Springer vol. 162 145–160(Springer, Berlin, Heidelberg., 2003).
11. Chaplin-Kramer, R. *et al.* Degradation in carbon stocks near tropical forest edges. *Nat. Commun.* **6**, 1–6 (2015).
12. Betts, M. G. *et al.* Global forest loss disproportionately erodes biodiversity in intact landscapes. *Nature*, **547**, 441–444 (2017).
13. Symes, W. S., Edwards, D. P., Miettinen, J., Rheindt, F. E. & Carrasco, L. R. Combined impacts of deforestation and wildlife trade on tropical biodiversity are severely underestimated. *Nat. Commun.* **9**, (2018).
14. Singh, S. *et al.* Modeling the spatial dynamics of deforestation and fragmentation using Multi-Layer Perceptron neural network and landscape fragmentation tool. *Ecol. Eng.* **99**, 543–551 (2017).
15. Bustamante, R. O. & Simonetti, J. A. Is *Pinus radiata* invading the native vegetation in Central Chile? Demographic responses in a fragmented forest. *Biol. Invasions*, **7**, 243–249 (2005).
16. Ripple, W. J. *et al.* Extinction risk is most acute for the world's largest and smallest vertebrates. *Proc. Natl. Acad. Sci. U. S. A.* **114**, 10678–10683(2017).
17. Shaffer, L. J., Khadka, K. K., Van Den Hoek, J. & Naithani, K. J. Human-elephant conflict: A review of current management strategies and future directions. *Front. Ecol. Evol*, **6**, 1–12 (2019).
18. Desai, A. A. & Riddle, H. S. Human -Elephant Conflict in Asia(2015).
19. Thouless, C. R. *et al.* African elephant status report 2016: an update from the African elephant database. Occasional paper series of the IUCN Species Survival Commission. IUCN Species Survival Comm. vi + 309pp(2016).
20. Leimgruber, P. *et al.* Fragmentation of Asia's remaining wildlands: Implications for Asian elephant conservation. *Anim. Conserv.* **6**, 347–359 (2003).
21. Koirala, R. K., Raubenheimer, D., Aryal, A., Pathak, M. L. & Ji, W. Feeding preferences of the Asian elephant (*Elephas maximus*) in Nepal. *BMC Ecol*, **16**, 1–9 (2016).
22. Sukumar, R. A brief review of the status, distribution and biology of wild Asian elephants *Elephas maximus*. *Int. Zoo Yearb*, **40**, 1–8 (2006).
23. Baskaran, N. Ranging and Resource Use by Asian elephant in Nilgiri Biosphere Reserve Southern India(1998).
24. Branco, P. S. *et al.* Determinants of elephant foraging behaviour in a coupled human-natural system: Is brown the new green? *J. Anim. Ecol.* **88**, 780–792 (2019).
25. Fernando, P. *et al.* Ranging behavior of the Asian elephant in Sri Lanka, **73**, 2–13 (2008).
26. Naha, D. *et al.* Landscape predictors of human–leopard conflicts within multi-use areas of the Himalayan region. *Sci. Rep.* **10**, (2020).
27. DNPWC. *The Elephant Conservation Action Plan for Nepal*. (2009).
28. Ram, A. K. & Acharya, H. Status distribution and habitat use by Asian elephants in Nepal. *A compendium of Conservation Bulletin published by Department of National Parks and Wildlife conservation, Nepal* 155–160(2020).
29. ten Velde, P. A Status Report of Nepal's Wild Elephant Population(1997).
30. Ram, A. K. *et al.* Patterns and determinants of Elephant attacks on humans in Nepal. *Authorea Preprint*, (2021).

31. Wikramanayake, E. *et al.* Designing a conservation landscape for tigers in human-dominated environments. *Conserv. Biol*, **18**, 839–844 (2004).
32. Smith, J. L. D. & Mishra, H. R. Status and distribution of Asian Elephants in Central Nepal. *Oryx*, **26**, 34–38 (1992).
33. Shrestha, M. N., Shrestha, K. & Dhakal, T. R. Hatti byabasthapan yojana tarujma pratibedan (Report on Planning for Elephant Management). Kathmandu: Janchbujh kendra bibhag raj durbar (Department Investigation Center, Nepali Royal Palace (in Nepali version)). (HMGN palace investigation centre, Principal Secretariat of His Majesty King, Royal Palace, Kathmandu, Nepal (in Nepali version) 1985).
34. Kharel, F. R. The challenge of managing domesticated Asian elephants in Nepal. in *Giants on our Hands* (Proceedings of the international workshop on the domesticated Asian elephant) 103–103 (FAO Regional Office for Asia and the Pacific of United Nations, Maliwan Mansion Phra Atit Road, Bangkok 10200 Thailand, 2002).
35. Gee, E. P. Report on a Survey of Rhinoceros Area of Nepal, prepared for the survival service commission of the International Union for the Conservation of Nature and Natural resources.(1959).
36. MoFSC. *Strategy and Action Plan 2015–2025 for Terai Arc landscape, Nepal*. (2015).
37. Subedi, N. *et al.* *Progress Report on Faunal Biodiversity Assessment in Chure Range of Nepal* (President Chure-Terai Madhesh Conservation Development Board and National Trust for Nature Conservation, Khumaltar, Lalitpur, 2021).
38. GoN/PCTMCDB. *President Chure-Terai Madhesh Conservation and Management Master Plan*. (2016).
39. Chaudhary, B. *et al.* Detailed Final Report Report with major findings (Part- I). 1–19(2018).
40. CBS. *National Population Census 2011, Central Bureau of Statistics* vol. 08 (Central Bureau of Statistics Ramshah Path, Thapathali Kathmandu, Nepa, 2012).
41. Hamilton, A. C. & Radford, E. Identification and Conservation of Important Plant Areas for Medicinal Plants in the Himalaya. Project and Workshop Report (Plantlife International (Salisbury, UK) and Ethnobotanical Society of Nepal (Kathmandu, Nepal, 2007).
42. DFRS. *State of Nepal's Forests. Forest Resource Assessment (FRA) Nepal, Department of Forest Research and Survey (DFRS). Kathmandu, Nepal*. (Ministry of Forest and Soil Conservation, Nepal, 2015). doi:978-9937-8896-3-6.
43. Chaudhary, R. P., Uprety, Y. & Rimal, S. K. Deforestation in Nepal: Causes, Consequences, and Responses. *Biological and Environmental Hazards, Risks, and Disasters*, <https://doi.org/10.1016/B978-0-12-394847-2.00020-6> (2016).
44. Neupane, D., Johnson, R. L. & Risch, T. S. How do land-use practices affect human–elephant conflict in nepal? *Wildlife Biol*. 2017, wlb.00313 (2017).
45. Acharya, K. P., Paudel, P. K., Jnawali, S. R., Neupane, P. R. & Köhl, M. Can forest fragmentation and configuration work as indicators of human–wildlife conflict? Evidences from human death and injury by wildlife attacks in Nepal. *Ecol. Indic*, **80**, 74–83 (2017).
46. DNPWC. Elephant Conservation Action Plan of Nepal (2010–2019). 1–30 (2010).
47. Wilcove, D. S., McLellan, C. H. & Dobson, A. P. Habitat Fragmentation in the Temperate zone. in *Conservation Biology (The Science of Scarcity and Diversity)* 237–256 (1986).
48. FAO. *State of the World's Forests. Food and Agriculture Organization of The United Nations, Rome* (2014).
49. Padalia, H. *et al.* Assessment of historical forest cover loss and fragmentation in Asian elephant ranges in India. *Environ. Monit. Assess.* **191**, (2019).
50. Sudhakar Reddy, C. *et al.* Quantification and monitoring of deforestation in India over eight decades (1930–2013). *Biodivers. Conserv*, **25**, 93–116 (2016).
51. Kaim, D. *et al.* Broad scale forest cover reconstruction from historical topographic maps. *Appl. Geogr*, **67**, 39–48 (2016).
52. Kaim, D. *et al.* Uncertainty in historical land-use reconstructions with topographic maps. *Quaest. Geogr*, **33**, 55–63 (2014).
53. Gorelick, N. *et al.* Google Earth Engine: Planetary-scale geospatial analysis for everyone. *Remote Sens. Environ*, **202**, 18–27 (2017).
54. Wang, Y. *et al.* Mapping tropical disturbed forests using multi-decadal 30 m optical satellite imagery. *Remote Sens. Environ*, **221**, 474–488 (2019).
55. Huang, H. *et al.* Mapping major land cover dynamics in Beijing using all Landsat images in Google Earth Engine. *Remote Sens. Environ*, **202**, 166–176 (2017).
56. Midekisa, A. *et al.* Mapping land cover change over continental Africa using Landsat and Google Earth Engine cloud computing. *PLoS One*, **12**, 1–15 (2017).
57. Zurqani, H. A., Post, C. J., Mikhailova, E. A., Schlautman, M. A. & Sharp, J. L. Geospatial analysis of land use change in the Savannah River Basin using Google Earth Engine. *Int. J. Appl. Earth Obs. Geoinf*, **69**, 175–185 (2018).
58. Rodriguez-Galiano, V. F., Ghimire, B., Rogan, J. & Chica-Olmo, M. & Rigol-Sanchez, J. P. An assessment of the effectiveness of a random forest classifier for land-cover classification. *ISPRS J. Photogramm. Remote Sens*, **67**, 93–104 (2012).
59. Joshi, R., Singh, R., Pushola, R. & Negi, M. S. Reproductive behaviour of wild Asian Elephants *Elephas maximus* in the Rajaji National Park, North-West India. *Nat. Sci*, **1**, 77–84 (2009).
60. Reddy, C. S., Sreelekshmi, S., Jha, C. S. & Dadhwal, V. K. National assessment of forest fragmentation in India: Landscape indices as measures of the effects of fragmentation and forest cover change. *Ecol. Eng*, **60**, 453–464 (2013).
61. ESRI. ArcGIS desktop 10.5. ESRI & Redland California (2016).
62. Puyravaud, J. P. Standardizing the calculation of the annual rate of deforestation. *For. Ecol. Manage*, **177**, 593–596 (2003).
63. Elkie, P., Rempel, R. & Carr, A. *Patch analyst user's manual. Ont. Min. Natur. Resour. Northwest Sci. & Technol. Thunder Bay, Ont. TM-002*, 16. (1999).
64. Vogt, P. *et al.* Mapping spatial patterns with morphological image processing. *Landsc. Ecol*, **22**, 171–177 (2007).
65. Dutta, K., Sudhakar Reddy, C., Sharma, S. & Jha, C. S. Quantification and monitoring of forest cover changes in Agasthyamalai Biosphere Reserve, Western Ghats, India (1920–2012). *Curr. Sci*, **110**, 508–520 (2016).

66. Shapiro, A. C., Aguilar-Amuchastegui, N., Hostert, P. & Bastin, J. F. Using fragmentation to assess degradation of forest edges in Democratic Republic of Congo. *Carbon Balance Manag.* **11**, (2016).
67. Reddy, C. S. *et al.* Assessment and monitoring of deforestation and forest fragmentation in South Asia since the 1930s. *Glob. Planet. Change*, **161**, 132–148 (2018).
68. Reddy, C. S. *et al.* Quantifying nationwide land cover and historical changes in forests of Nepal (1930–2014): implications on forest fragmentation. *Biodivers. Conserv.*, **27**, 91–107 (2018).
69. Aulestia, M. J. S. Understanding land use and land cover dynamics in the Chure region of Nepal: Integrating physiographic, socio-economic and policy drivers (2019).
70. Laurie, A. The Ecology and Behaviour of the Greater One-Horned Rhinoceros, a dissertation submitted to the University of Cambridge for the degree of Doctor of Philosophy. Behaviour (1978).
71. Rimal, S., Adhikari, H. & Tripathi, S. Habitat suitability and threat analysis of Greater One-horned Rhinoceros *Rhinoceros unicornis* Linnaeus, 1758 (Mammalia: Perissodactyla: Rhinocerotidae) in Rautahat District, Nepal. *J. Threat. Taxa*, **10**, 11999–12007 (2018).
72. Puyravaud, J. P., Gubbi, S., Poornesha, H. C. & Davidar, P. Deforestation Increases Frequency of Incidents With Elephants (*Elephas maximus*). *Trop. Conserv. Sci.* **12**, (2019).
73. Puyravaud, J. P., Davidar, P. & Laurance, W. F. Cryptic destruction of India's native forests. *Conserv. Lett.*, **3**, 390–394 (2010).
74. Sampson, C. *et al.* Effects of illegal grazing and invasive *Lantana camara* on Asian elephant habitat use. *Biol. Conserv.*, **220**, 50–59 (2018).
75. Peh, K. S. H. Invasive species in Southeast Asia: The knowledge so far. *Biodivers. Conserv.*, **19**, 1083–1099 (2010).
76. Lamichhane, B. R. *et al.* Using interviews and biological sign surveys to infer seasonal use of forested and agricultural portions of a human-dominated landscape by Asian elephants in Nepal. *Ethol. Ecol. Evol.*, **30**, 331–347 (2018).
77. Acharya, K. P., Paudel, P. K., Neupane, P. R. & Köhl, M. Human-wildlife conflicts in Nepal: Patterns of human fatalities and injuries caused by large mammals. *PLoS One*, **11**, 1–18 (2016).
78. Carter, N. H., Shrestha, B. K., Karki, J. B., Pradhan, N. M. B. & Liu, J. Coexistence between wildlife and humans at fine spatial scales. *Proc. Natl. Acad. Sci. U. S. A.* **109**, 15360–15365 (2012).
79. Choudhury, A. Human–Elephant conflicts in northeast India. *Hum. Dimens. Wildl.*, **9**, 261–270 (2004).
80. Sukumar, R. The Asian Elephant: Ecology and Management. **8**, 254 (1989).
81. Reddy, C. S. *et al.* Conservation priorities of forest ecosystems: Evaluation of deforestation and degradation hotspots using geospatial techniques. *Ecological Engineering* vol. 91 (2016).
82. Nandy, S., Kushwaha, S. P. S. & Dadhwal, V. K. Forest degradation assessment in the upper catchment of the river Tons using remote sensing and GIS. *Ecol. Indic.*, **11**, 509–513 (2011).
83. Suba, R. B. *et al.* Rapid expansion of oil palm is leading to human–elephant conflicts in north Kalimantan province of Indonesia. *Trop. Conserv. Sci.* **10**, (2017).
84. Naha, D., Sathyakumar, S., Dash, S., Chettri, A. & Rawat, G. S. Assessment and prediction of spatial patterns of human–elephant conflicts in changing land cover scenarios of a human-dominated landscape in North Bengal. *PLoS One* **14**, (2019).
85. Laudari, H. K., Aryal, K. & Maraseni, T. A postmortem of forest policy dynamics of Nepal. *Land use policy* **91**, (2020).
86. Gee, E. P. Report on a brief survey of the wild life resources of Nepal, including the rhinoceros. *Oryx*, **7**, 67–76 (1963).
87. Kanel, K. R. & Acharya, D. P. Re-inventing forestry agencies: institutional innovation to support community forestry in Nepal. Re-inventing forestry agencies: Experiences of institutional restructuring in Asia and the Pacific vol. 4 (FOOD AND AGRICULTURE ORGANIZATION OF THE UNITED NATIONS REGIONAL OFFICE FOR ASIA AND THE PACIFIC Bangkok 2008, 2008).
88. Dahal, G. R., Pokharel, B. K., Khanal, D. R. & Pokhrel, P. R. A framework for classifying subsistence production types of Nepal. *J. For. Livelihood*, **15**, 15–26 (2017).
89. Ranjit, Y. History of Forest Management in Nepal: An Analysis of Political and Economic Perspective. *Econ. J. Nepal*, **42**, 12–28 (2019).
90. Adhikari, J. & Dhungana, H. The State and Forest Resources: An Historical Analysis of Policies Affecting Forest Management in the Nepalese Tarai. *HIMALAYA, J. Assoc. Nepal Himal. Stud.*, **29**, 43–56 (2010).

Figures

Figure 1

The geographical location of Nepal and the study area (Chure Terai Madhesh Landscape).

Figure 2

Overall methodological framework adopted for this study.

a)

b)

c)

Figure 3

Forest cover change in the Asian elephant habitat (the Chure Terai Madhesh Landscape), Nepal during the time periods a) 1930–1975, b) 1975–2000, 2000–2020.

Figure 4

Habitat (forest) fragmentation of Asian elephants in the Chure Terai Madhesh Landscape, Nepal. Inset shows an enlarged view of habitat fragmentation in four different periods (1930, 1975, 2000 and 2020) at that particular location.

Supplementary Files

This is a list of supplementary files associated with this preprint. Click to download.

- [SupplementaryTablesandFigures.docx](#)