Trees, Forests and People 2 (2020) 100039

Contents lists available at ScienceDirect

Trees, Forests and People

journal homepage: www.elsevier.com/locate/tfp

Documenting the land use pattern in the corridor complexes of Kaziranga National Park using high resolution satellite imagery

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ARTICLE INFO

Keywords:
Forest fragmentation
Camera trap
Corridor mapping
Kaziranga National Park
Wildlife conflict

ABSTRACT

Kaziranga National Park (KNP) in Assam, India, is a protected area of global prominence as it provides habitat to the largest population of the Indian Rhinoceros in the world and is also special as it has a diverse human population from different cultures surrounding the national park. Conservation and management of the park is becoming very complex with the passage of time due to a range of issues including the increase in wildlife as well as human population and developments in the adjoining areas. There is no buffer zone in the park and animals historically, have used the adjoining forests and highlands as refuge from time to time to escape the onslaught of seasonal floods. Developments and growth of human settlements have constricted the areas available for free movement of animals from and to the park in many sectors and at present there are 9 prominent tracts which are used by the animals for their movement to adjoining habitats and in many portions, both humans and wildlife use the same areas. There are at least five common complexes that are used by wildlife for their movement in and around the Kaziranga NP and detailed information regarding the land use and land cover pattern within these corridor complexes which are very vital for the security of the park, is not available. The present study uses high resolution satellite images (IRS P6 LISS IV and LISS III) for 2002 and 2013 and extensive field survey methods for documenting the pattern of the existing land use/land cover of the corridor complexes. Camera trap-based monitoring, interaction with the local people and GPS field surveys were conducted during the 2015–16 period for this study. Land use land cover change analysis and forest fragmentation map was prepared to understand the nature of anthropogenic disturbance to the forest cover of the corridor complexes. The result reveals that most of the corridor complexes have a very mixed type of land cover, which advocates very careful planning to ensure that both humans and animals use the area sustainably. The NH-37 which runs on the south of the Kaziranga National Park has become a zone of escalating developmental activities for the local population as well as the tourists. Few corridors for animal movement, which have become almost non-functional due to regular increase of anthropogenic activities in few important areas.

1. Introduction

Habitat loss, fragmentation and isolation have been noted as the most crucial threats to and the most common causes of the loss of faunal and floral species of the earth these days (Babbar et al., 2020). For this reason, it is crucial to develop specific strategies of conservation (Pokhriyal et al., 2020; Areendran et al., 2020). Corridors are important geographic functions for biological conservation and biodiversity assessment. At a broader scale, corridors are considered to occupy a particular niche in terms of ecological conservation (Varma et al., 2008). The role and vitality of corridors for species conservation has been well documented, but there has been confusion about the proper definition of a corridor (Varma et al., 2008). Corridors are generally understood to be linear landscape elements known to facilitate species movement across habitat patches in a particular landscape that promote increase in species and genetic diversity among different habitats (Varma et al., 2008). It links central biological regions, permitting animal movement, keeps flora and fauna towards land fragmentation (Vogt et al., 2007). The structure and functions of corridors vary according to the focal species concerned, such as the factors that influence their movement pattern (Srivastava and Tyagi, 2016; Yadav et al., 2020). The patterns for seasonal migration, availability of prey and food, requirements for

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https://doi.org/10.1016/j.tfp.2020.100039
Received 3 July 2020; Received in revised form 22 September 2020; Accepted 23 September 2020
Available online 28 September 2020

water are different for different species and hence, corridors maintaining connectivity between habitat patches must be different in their function, form and context (Bora et al., 2015; Srivastava and Tyagi, 2016). In growing economies like India, with the boom in urbanization, human settlements are shifting closer to forests, clearing habitats of flora and fauna. This has resulted in habitat fragmentation, reducing diversity, shrinking corridors between protected regions (PA's) (Joshi et al., 2011). Linear interventions like roads and railways are major contributors to habitat fragmentation and degradation which results in destruction of corridors for animal movement and loss of habitat connectivity between diverse forest types of a protected region (Hess and Fischer, 2001; Qureshi et al., 2011)

Geospatial science has turned out to be a useful device for tracking ecological impacts, changes in corridors and offering capabilities to look at and interpret floral and faunal habitat information on many time scales (Nandy et al., 2007). Wildlife corridor tracking runs parallel to any sort of land cover mapping. With rising concerns around the integrity of the natural world and conservation areas, geospatial strategies have presumed critical significance. In this paper, the prominent corridor complexes connecting Kaziranga NP to adjoining habitats are mapped, as they act as lifelines for the survival of wildlife in the park, primarily, elephants, tigers and rhinos. The entire world is considered to be inter-connected and different habitat patches encompassing different species need to be connected using different paths in order to maintain species survival which is of prime importance for maintaining ecological balance (Richard, 2011; Sahana et al., 2017; Ahmed et al., 2017).

The KNP is a well-known protected area in Assam situated on the banks of the river Brahmaputra in the foothills of the Karbi Anglong (KA) Hills (Gogoi, 2015). It is recognized as a UNESCO World Heritage Site and as a place that hosts the highest population of the Greater One-horned Rhinoceros. The present park area is distributed over four districts of Assam, namely, Golaghat, Nagaon, Sonitpur and Biswanath. The forest patches that surround the KNP, form a continuous landmass extending across the nearby Karbi Anglong district to the south that provides vital habitat and appropriate conditions for wild animals in the Kaziranga-Karbi Anglong Landscape (KKL) (Gogoi, 2015).

The present study used high-resolution satellite images to identify the present composition of land use land cover in prominent sectors used by wildlife for their identification as corridor complexes. We have assessed the impact of two major developmental entities in terms of assessing and mapping the corridor complex due to the dynamics of forest cover and the anthropogenic pressure within the landscape using geospatial approach. Two specific objectives in this study are: (1) to assess the spatial patterns and land use and land cover change in major wildlife corridor complexes and (2) to analyze the factor and degree of physical and anthropogenic disturbance to the forest cover of the corridor complex. The novelty of the present study is to assessed the degree of landscape and vegetation fragmentation in each of the corridor complexes to understand the implications of animal movement. We have demarcated the major corridor complexes based on animal use possibilities and used the Fragstats and Patch Analyst for to assessed the landscape fragmentation in and around the corridor complexes.

2. Study area

Kaziranga National Park was declared vide Govt. Notification No. FOR/WL/722/48/45, dated 11–02–74 with effect from 01 to 01–74 under the provisions of Assam National Parks Act 1968 with an area of 429.93 km^2. Administratively, the KNP in its original form was spread across Golaghat and Nagaon districts in the state of Assam, with the Brahmaputra River to the north and the Karbi-Anglong hills to the south (Talukdar, 1996). However, with the passage of time the park got extended with addition of areas and is currently also covered by the districts of Sonitpur and Biswanath with a total area of 884.43 km^2. It lies between latitudes 26° 30′ and 26° 45′N and longitudes 93° 05′ and 93° 40′E in the central part of Assam. The KNP is also recognized as an UNESCO World Heritage Site (Assam Forest Department, 2014). The area is a representation of an extravagant mosaic of grassland, woodland and water bodies which provides an ideal and critical habitat for many threatened mammals and birds including the Great Indian One-Horned Rhinoceros (*Rhinoceros unicornis*) (GoH), Bengal Tiger (*Panthera tigris*), Wild Buffalo (*Bubalis bubalis*), Asian Elephant (*Elephas maximus*) and Eastern Swamp Deer (*Rucervus duvaucelii ranjitsinhi*). The area houses the highest density of wild Bengal tigers. KNP in holds approx 67% (n = 2413 as per 2018) of the world's GoH population (*Rhinoceros unicornis*). Since the formation of the park, areas have been added to the park to provide more space to its wildlife. Till date, six areas have been added and the park presently has a total area of 884.44 km^2. As per UNESCO, it falls within the Burma Monsoon Forest (4.09.04) and the North-east Brahmaputra Valley (9A) Bio-geographical Province. It falls within the Indo-Malayan Terrestrial Eco-Zone and the Brahmaputra Valley Semi Evergreen Eco-Region. These unique values helped KNP to get inscribed on the World Heritage List in the year 1985 under criteria N (ix) and N (x) of the Natural World Heritage (Choudhury, 1999).

The entire KNP area has been formed by the alluvial deposits of the Brahmaputra river and its smaller tributaries. In the past, the adjoining forests of Karbi Anglong and grasslands of KNP formed one single ecological unit, an ideal habitat for rhinos and other wildlife with very few human habitations (WWF-India 2006). But with the gradual opening up of the area on both sides post the construction of National Highway (NH 37), the forest cover got fragmented resulting in the loss of connected natural forests and wild habitats ultimately resulting in the formation, identification and securing of wildlife corridors and passages. With the passage of time, threats to the existence of these passages for safe movement of wildlife have increased manifold and it is now a huge challenge to keep them well managed and secured. Historically, there existed large tracts of forests for animals to move from the plains of Kaziranga to its adjoining areas. However, with time, the contiguous forests have disappeared resulting in identification and formation of passages. The major corridor complexes which also includes the 9 prominent corridors of Kaziranga NP, identified for this study are identified as -

i The Amguri Corridor complex
ii The Mongkrakjuri – Kanchanjuri Corridor complex
iii The Haldhibari Corridor complex;
iv The Panbari Corridor complex; &
v The Kaziranga – Burachapori river corridor

KNP was finally declared vide Govt. Notification No. FOR/WL/722/48/45, dated 11–02–74 with effect from 01 to 01–74 under the provisions of Assam National Parks Act 1968 with an area of 429.93 km^2. Administratively the KNP is situated in the Golaghat and Nagaon districts in the state of Assam, with the Brahmaputra River to the North and the Karbi-Anglong hills to the South. It lies between Longitude 92°50′ E-92° 41′ E and Latitude 25°30′N-26°50′N. Kaziranga National Park is declared as a world heritage site. The area is a representation of extravagant mosaic of grassland, woodland and water bodies which provides an ideal and critical habitat for many threatened mammals and birds including the great Indian one-horned rhino (*Rhinoceros unicornis*), Bengal tiger (*Panthera tigris*), wild buffalo (*Bubalis bubalis*), Asian elephant (*Elephas maximus*) and eastern swamp deer (*Rucervus duvaucelii ranjitsinhi*). The area encompasses highest density of wild Bengal tigers. Kaziranga National Park (KNP) in Assam, India holds approx 67% (n = 2413 as per the 2018 estimates) of world's GoH population (*Rhinoceros unicornis*). Since the formation of the Park, areas have been added to the park to provide more space to its wildlife, till date six areas have been added and the park presently has a total area of 884.44 km^2. As per UNESCO, it falls within the Burma Monsoon Forest (4.09.04) and within the North-east Brahmaputra Valley (9A) Bio-geographical Province. It falls within the Indo-Malayan Terrestrial Eco-Zone, Brahmaputra Valley Semi Evergreen Eco-Region. The unique values helped Kaziranga National Park to get inscribed on the World Heritage List in the year 1985 under criteria N (ix) and N (x) of the Natural World Heritage (Yadava, 2014).

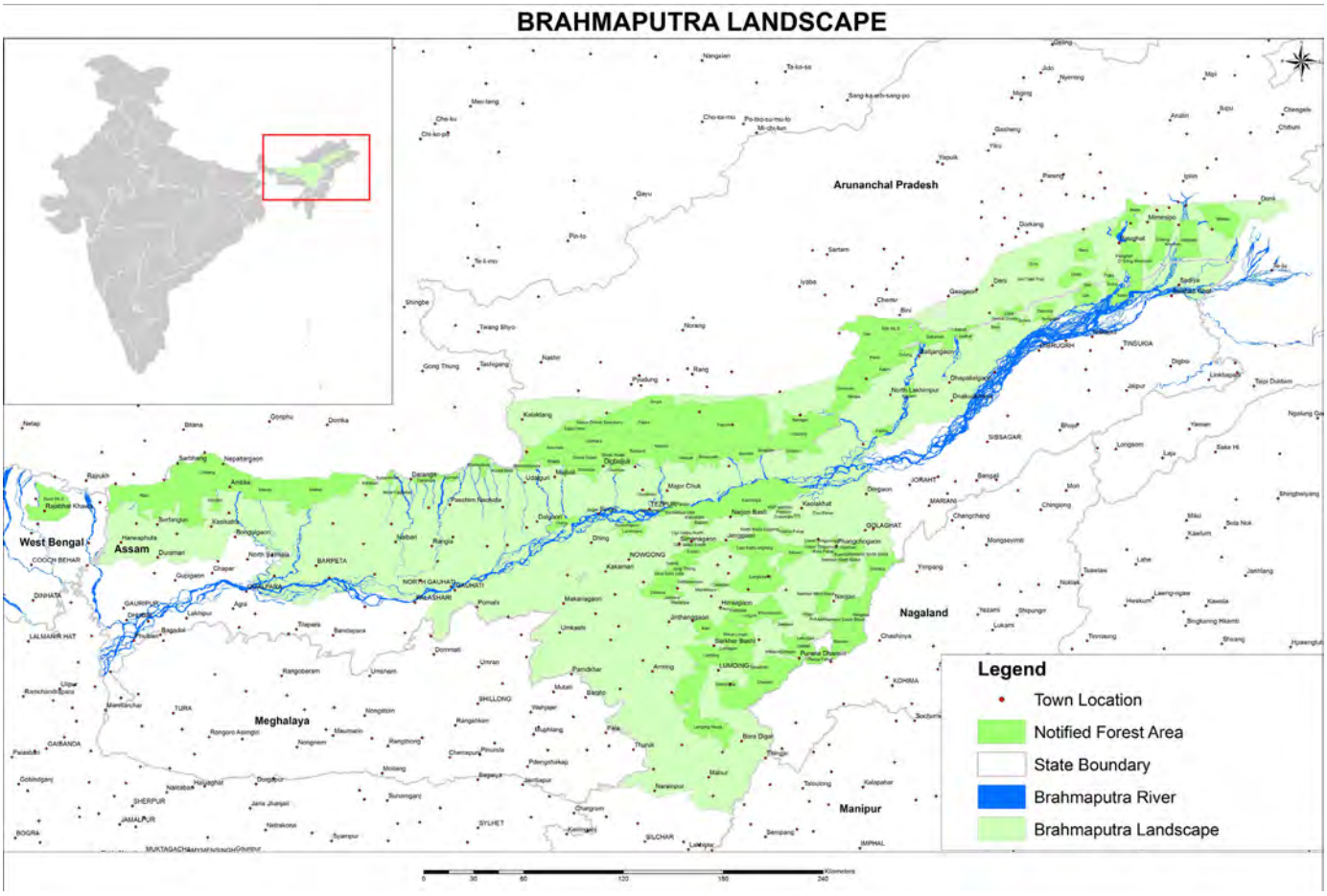

Fig. 1. Location of protected areas and notified forest area in Brahmaputra Landscape.

The entire Kaziranga National Park area has been formed by the alluvial deposits of the Brahmaputra river and its smaller tributaries. In the past, the adjoining forests of Karbi Anglong and grasslands of Kaziranga National Park formed one single ecological unit, an ideal habitat for rhinos and other wildlife with very few human habitations. But with gradual opening up of the area on both the sides of the present National Highway No.37, the forest cover got fragmented resulting in loss of natural wild habitat and ultimately resulting in wildlife corridors (Talukdar and Barman, 2003). With the passage of time the threat to the existence of these safe passage for wildlife has increased manifold and it is a huge challenge now to keep these well managed and protected. Historically there existed many stretches which were used by animals for moving from Kaziranga to its adjoining areas and many of these have now become almost non-functional due to anthropogenic pressure.

The North Karbi-Anglong Wildlife Sanctuary and the adjoining hilly forest areas to the south in the Karbi Anglong district are extremely important for the survival of Kaziranga and provides shelter to migrating and long ranging animals of the park, especially during periods of flood (Monier, 2006). The mighty river Brahmaputra flows from east to west along the northern part of the park and forms a part of the 6th addition to the park. Brahmaputra and its tributaries contribute to flooding of the park and in the process, enrich the soil and washes out waste material and water hyacinth (Eichhornia crassipes). The floods help rejuvenate Kaziranga's ecosystem and contribute positively. However, this also leads to forced migration of Kaziranga's wild mammals to the adjoining hills of Karbi Anglong located to its south adding to the value of the corridors.

A details geomorphological map (Fig. 3) for each corridor in the study area has been prepared to understand the physical setting and its relation with the forest degradation. The study area is situated in the flood plain of Brahmaputra river basin which is one of the most vulnerable floods affected area in India. So, most of the geomorphological features in the landscape are mostly related to the fluvial process and fluvial morphology. These are a total of 35 features pertaining to the diversity of the landscape. Features present include Oxbow lake, Meander Scar, Residual Hill, Synformal Hill, Channel Bar and many other as well. Paleochannels confirm the presence of a waterbody/stream/river that was previously present and still exists. Maximum area of Kaziranga National Park is situated in the alluvial flood plain with very low slope and it's an important consequence of frequent flood in this national park.

WWF-India through its Kaziranga - Karbi Anglong Landscape Conservation Programme (KKL) which is now a part of the Brahmaputra landscape since 2004, has been working to document and ensure the functionality of the corridors connecting Kaziranga to the adjoining habitats by undertaking various conservation activities taking the local population into confidence and also involving them in the process (WWF, 2008a). This is a challenging task, given that most parts of these corridor complexes are inhabited by villages, tourist facilities and other infrastructure have grown rapidly over the last decade dotting the entire space. Further, the existence of NH 37 cutting across these major corridors leads to a barrier effect for the wild animals with increasing traffic making the life of animals more precarious. The ongoing land use changes to accommodate a growing population, increasing tourism and other development activities in the area are gradually posing a big challenge to the functionality of these corridors complexes (WWF, 2008b). As per a recent report, a Government constituted committee formed in 2019 has delineated nine major corridors connecting Kaziranga NP to the areas to the south and most of those also forms a part of the corridor complexes considered under this present study completed during 2015–2016.

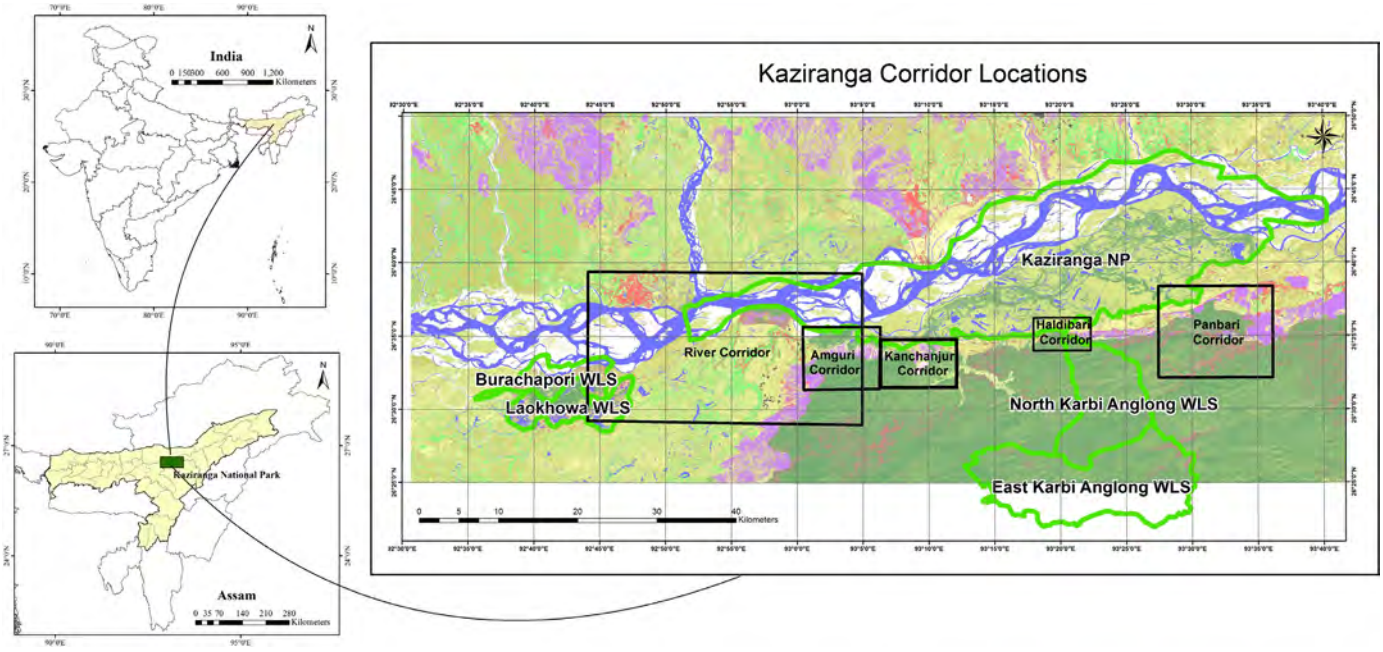

Fig. 2. Location map of study area.

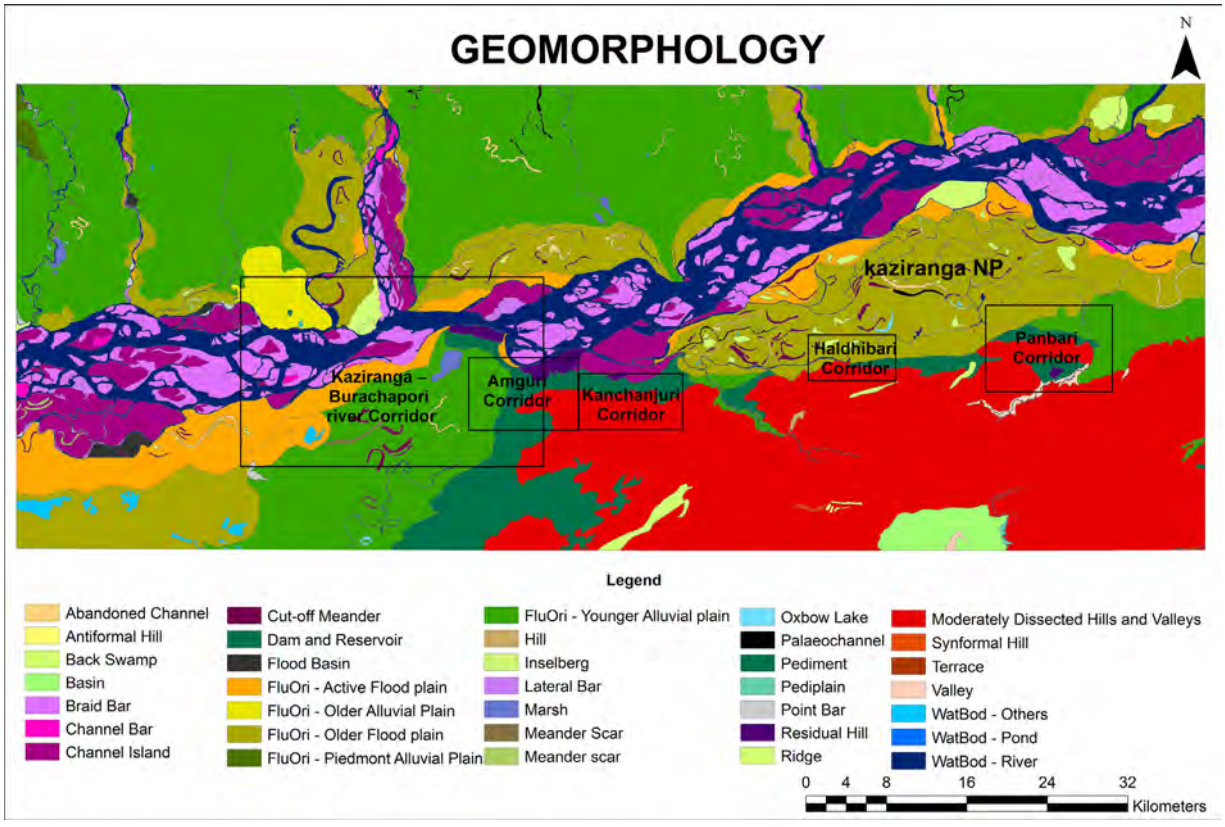

Fig. 3. A details geomorphological map for each examined corridor.

3. Database and methodology

In this study, digital data has been acquired from satellite imagery (IRS-P6, LISS- IV) of 5.8 m spatial resolution for the year 2013. The land use land cover (LULC) map of the study area was prepared using a geo-coded image which was used in the form of False Colour Composite. Information was extracted from the satellite image by applying visual image interpretation techniques. Two rounds of ground truthing surveys were conducted for performing an accurate image classification. Different elements of visual image interpretation elements like shape, size, texture, association, pattern tone (or hue) etc. were used for identification of various land use and land cover classes in the study area. A

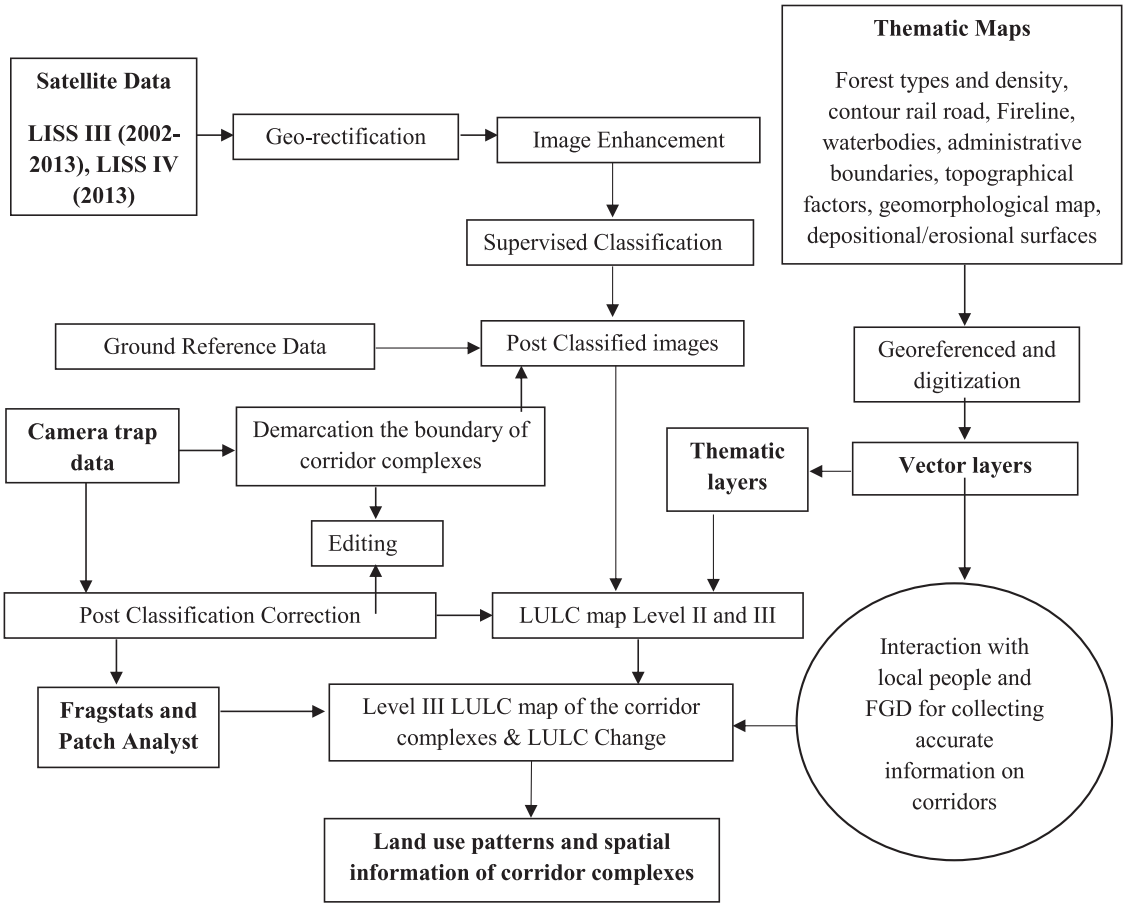

Fig. 4. Methodological framework of the study.

False color Composite (FCC) was prepared by layer stacking the Near Infra-Red (NIR), Red and Green bands of the imagery (Sahana and Sajjad, 2017).

For mapping the major corridor complexes of Kaziranga based on actual animal use and historical evidences, five broad areas have been identified with an aim to capture the information practically. The corridors connecting Kaziranga identified based on use by animals is not very simple as they are spread all throughout the area, illustrating a very complex pattern. To make the understanding better, all major movement stretches have been clubbed to form a broad complex to undertake this mapping exercise which in no way confirms that the entire complex is one single corridor or is used by wildlife extensively and exclusively (WWF, 2008c).

Geometric correction of the satellite images includes geometric distortions caused due to the sensors, earth geometric variations and conversion of data to latitude and longitude on the Earth's surface (Macleod and Congalton, 1998). In this study, registration of satellite imagery was executed by using the nearest- neighbour algorithm. The raster image was geo-coded according to the appropriate projection using suitable projection parameters, which was later, rectified by selecting GCPs throughout the study area with a root-mean-square (RMS) error of 0.002 pixels (image to image geo-rectification). Geo-referenced image of the study area was used to extract the Kaziranga-Kanchanjuri-Karbi-Anglong Corridor. Histogram equalization and stretch enhancement techniques were applied to the study area for better and accurate interpretation of different features in the satellite imagery. In the present study, a commonly used method was performed, that is supervised classification of the image. In supervised classification, training areas of different surface cover types of interest are taken. The selection of appropriate training areas is based on the analyst's knowledge about the geographical area. Thus, the analyst is "supervising" the classification of a set of specific classes (Sahana and Sajjad, 2019). The numerical information in all spectral bands for all the pixels comprising these areas is used to "train" the computer to distinguish spectrally similar areas for each class. The computer makes use of special programs or algorithms (of which there are several variations), in order to determine the numerical "signatures" for each training class (Lillesand and Kiefer, 2000). Land use land cover change map was prepared using change matrix technique to understand the intensity and diversity of land use dynamic in the study area (Sahana et al., 2018a; Dhali et al., 2019).

In the study, maximum likelihood classifier (MLC) algorithm was used. The classification error was reduced by reclassifying the generalized images which improved the classification accuracy. KAPPA Index (Cohen, 1960) and KHAT statistic was used for accuracy assessment. Cohen's kappa index is a multi-nominal sampling model used to measure accuracy assessment (Galton, 1892; Sahana et al., 2018b). The overall accuracy of land use/land cover classes was 88.46% and kappa coefficient value was 0.88.

Stratified random sampling with probability proportion to the size (PPS) was used for ground truthing survey. Camera trap was used to track wild animals within the most possible locations in the corridors. We have conducted several face-to-face interactions with elderly villagers nearest to the wildlife corridors to document the perception of the local people.

Normalised different vegetation index (NDVI) and unsurpervised classification was carried out to differentiate the sorest and non-forest areas in the study area (Sahana et al., 2016; Dutta et al., 2017). FRAGSTATS tool and Landscape fragmentation model was used to assessed the degree of the forest fragmentation in the study area (Vogt et al., 2007; Sahana et al., 2015a).

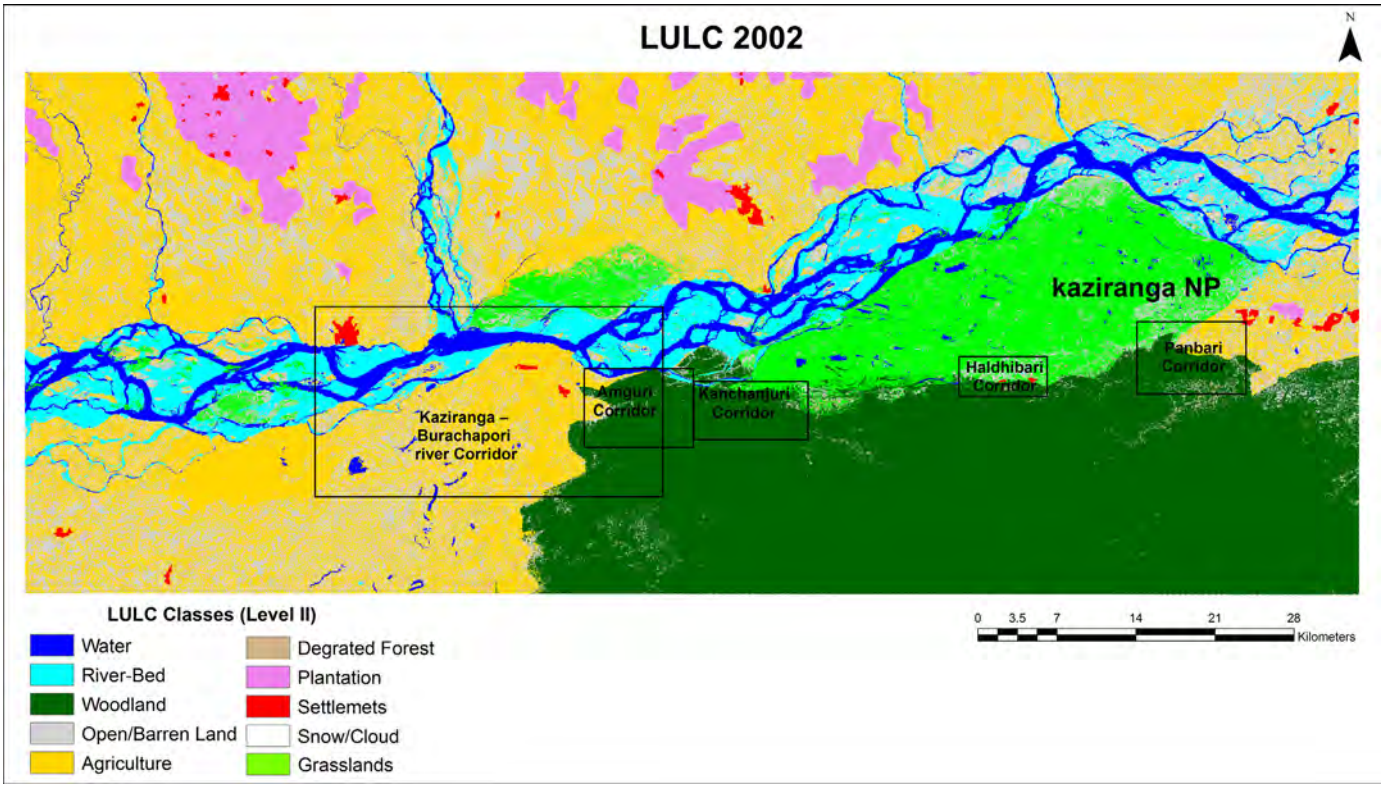

Fig. 5. Land use land cover map (Level II) of the study area 2002.

Table 1
Details of spatial and non-spatial data used for this study.

Data	Data Types	Source of Data	Details about Data	Period
IRS-P6, LISS- IV	Spatial	ISRO P6 satellite images	(5.8 m resolution)	2013
Topographical sheet	Spatial	Survey of India	1:50,000	1956
Base map	Spatial	Census of India/ Survey of India	polygon shape	2011
Primary field survey	GPS points	Primary field survey	Primary field survey and ground truth	2015

Table 2
Area under different land use/land cover classes (2002 and 2013).

Class Name	2002 (LISS 3)		2013 (LISS 3)	
	Area (Sq. Km)	Area (%)	Area (Sq. Km)	Area (%)
Water	279.1	5.1	475.5	8.7
River Bed	411.7	7.5	395.4	7.2
Woodland	1353.0	24.8	1200.1	22.0
Open Land	1029.5	18.8	1414.4	25.9
Agriculture	1638.9	30.0	1212.0	22.2
Degraded Forest	7.8	0.1	183.0	3.3
Plantation	228.4	4.2	237.0	4.3
Settlement	23.1	0.4	23.8	0.4
Grassland	492.6	9.0	322.9	5.9
Total	5464.0	100.0	5464.0	100.0

4. Result and discussion

4.1. Level II LULC classification of the study area

The Land Use Land Cover mapping for the landscape was carried out for the years 2002 and 2013. The land use/cover maps prepared for years 2002 and 2013 were classified into 9 classes, namely; water, woodland, agriculture, degraded forest, plantation, settlement, grassland, open land, riverbed. Figs. 5–7 and Table 2 depicts that the area covered by waterbodies increased in the study area from 279.1 sq. km. in 2002 to 475.5 sq. km in 2013. There was a decrease in the area covered by woodland from 1353 sq. km in 2002 to 1200 sq. km in 2013. There was a drastic increase in the areas covered by degraded forest from 7.8 sq. km in 2002 to 183.3 sq. km in 2013. This depicts that the habitat of the landscape has been undergoing degradation due to the influence of various biotic and abiotic pressures. The area covered by plantations has also shown an increase from 228.4 sq. km in 2002 to 237 sq. km in 2013. The area covered by grasslands has decreased through the years from 492.6 sq. km in 2002 to 322.9 sq. km in 2013. The shrinkage in grassland has happened due to many of the reasons such as degradation of habitat, fragmentation, overgrazing etc. The area covered by agriculture decreased from 1638.9 sq. km in 2002 to 1212 sq. km in 2013. Also, the area covered by open land decreases from 1029.5 sq. km in 2002 to 1414.4 sq. km in 2013. Same trend has been observed in the area covered by riverbed that decreased from 411.7 sq. km in 2002 to 395.4 sq. km in 2013. This is mainly because the area covered by waterbody has increased. There was a slight increase in the area covered by settlements from 23.1 sq. km in (2002) to 23.8 sq. km (2013).

4.2. Level III LULC classification of corridor complexes

Thirteen land use / land cover classes of Kaziranga corridor complexes were identified namely; (1) Dense Forest, (2) Open Forest, (3) Tea plantation, (4) Grass land, (5) Agriculture, (6) Fallow land, (7) Open land/Sand Bar, (8) Tree canopy, (9) Water, (10) Built-up area, (11) Mining area, (12) Rubber plantation, (13) Degraded/Open forest. The land

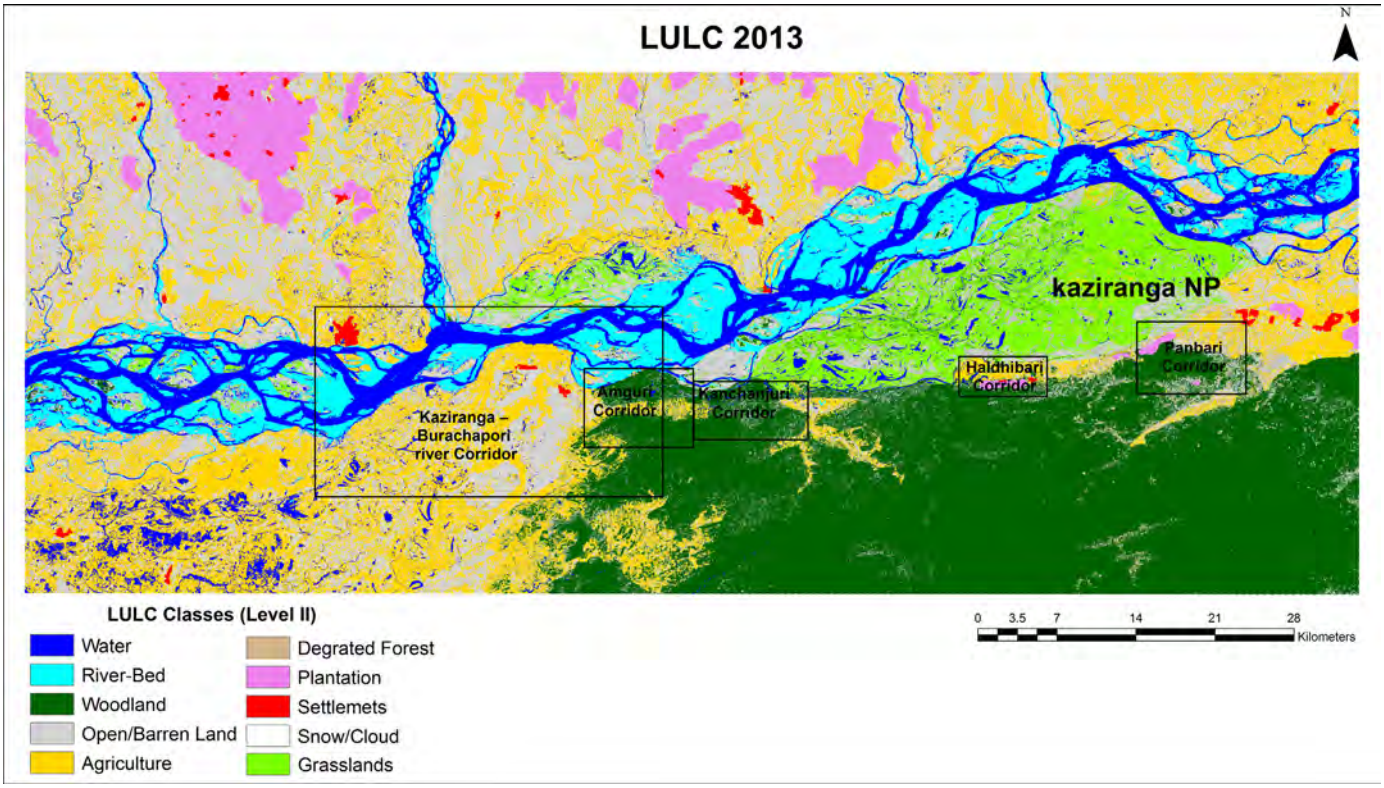

Fig. 6. Land use land cover map (Level II) of the study area 2013.

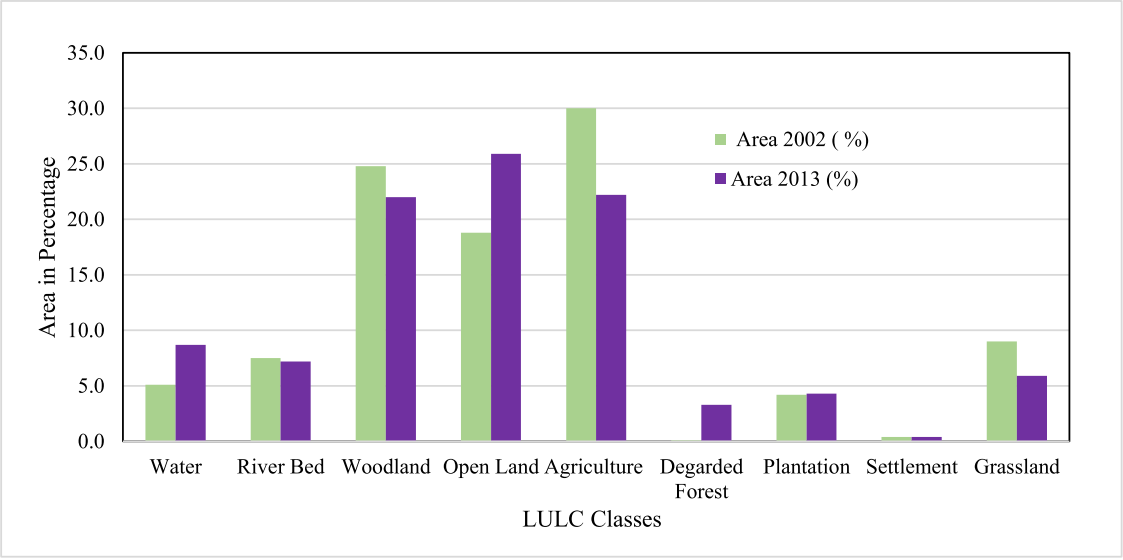

Fig. 7. Land use land cover change analysis of the study area (2002–2013).

use land cover map was prepared for the five major corridor complexes and finalized after rounds of ground truthing. The results of this analysis are discussed in the following sections:

4.2.1. The Amguri corridor complex

This corridor complex starts from Baghjan (near Baneswar mandir) in the west to Deosur bridge on NH 37 to the east. This complex extends between 26° 35′ 38.41″ N and 26° 31′ 22.15″ N latitude and 93° 00′ 24.71″ E and 93° 06′ 19.67″ E longitude and covers an area of about 77 km^2. This complex has at least three distinct passages used by wild animals and facilitates animal movement from the western parts of Kaziranga including the 1st addition and Kukurakata Reserve Forest to the north to the Bagser RF (hills) to the south under Kaliabor sub-division of Nagaon district. The spread of human habitation and tea estates is pretty significant in this complex and there is hardly any forest connectivity left for a secured passage to be used solely by animals and this space is shared by both humans and wildlife. This complex connects the KNP with the Bagser Reserve Forest and the adjoining forests of the Karbi Anglong to the south. It begins from Baneshwar, near Jakhalabandha Forest IB in the west which falls under the Nagaon Forest Division and stretches about 12 km up to the end of Burhapahar to the east along NH-37.

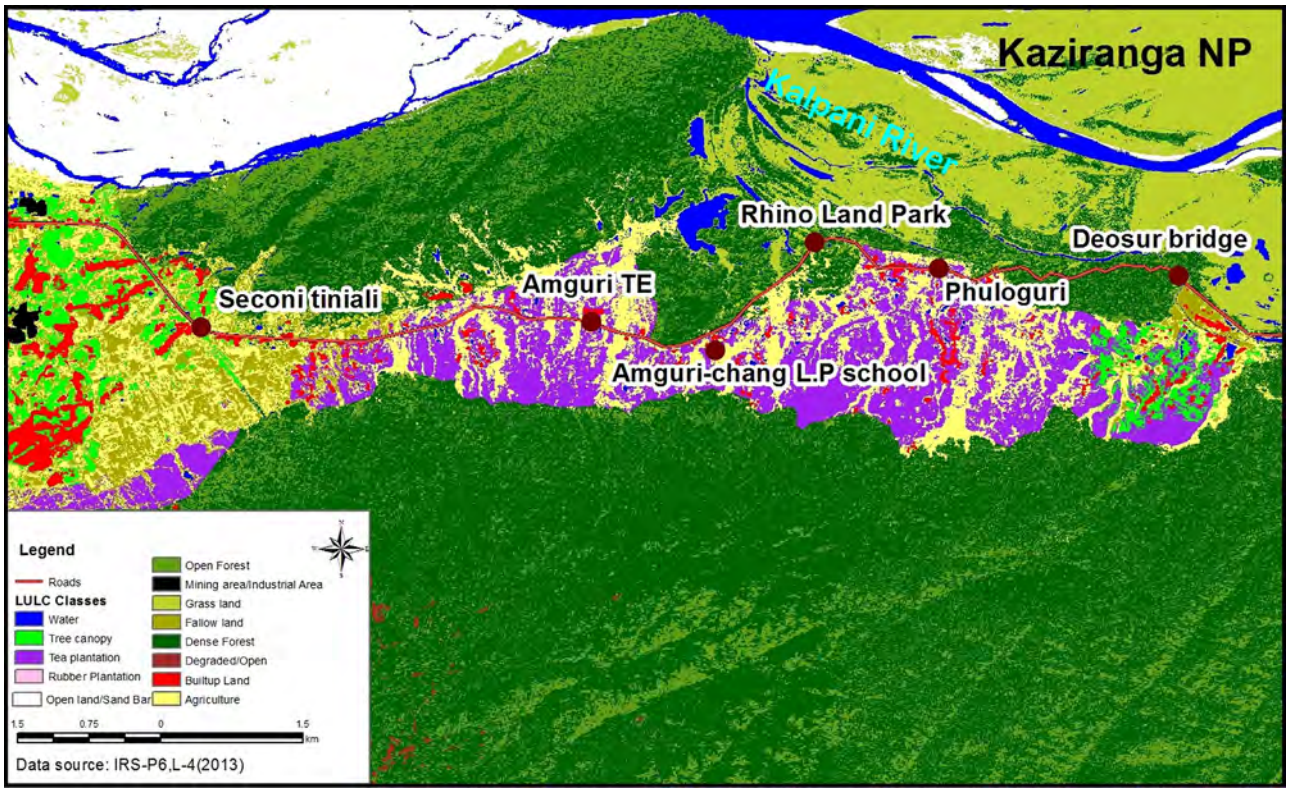

Fig. 8. Amguri corridor complex map.

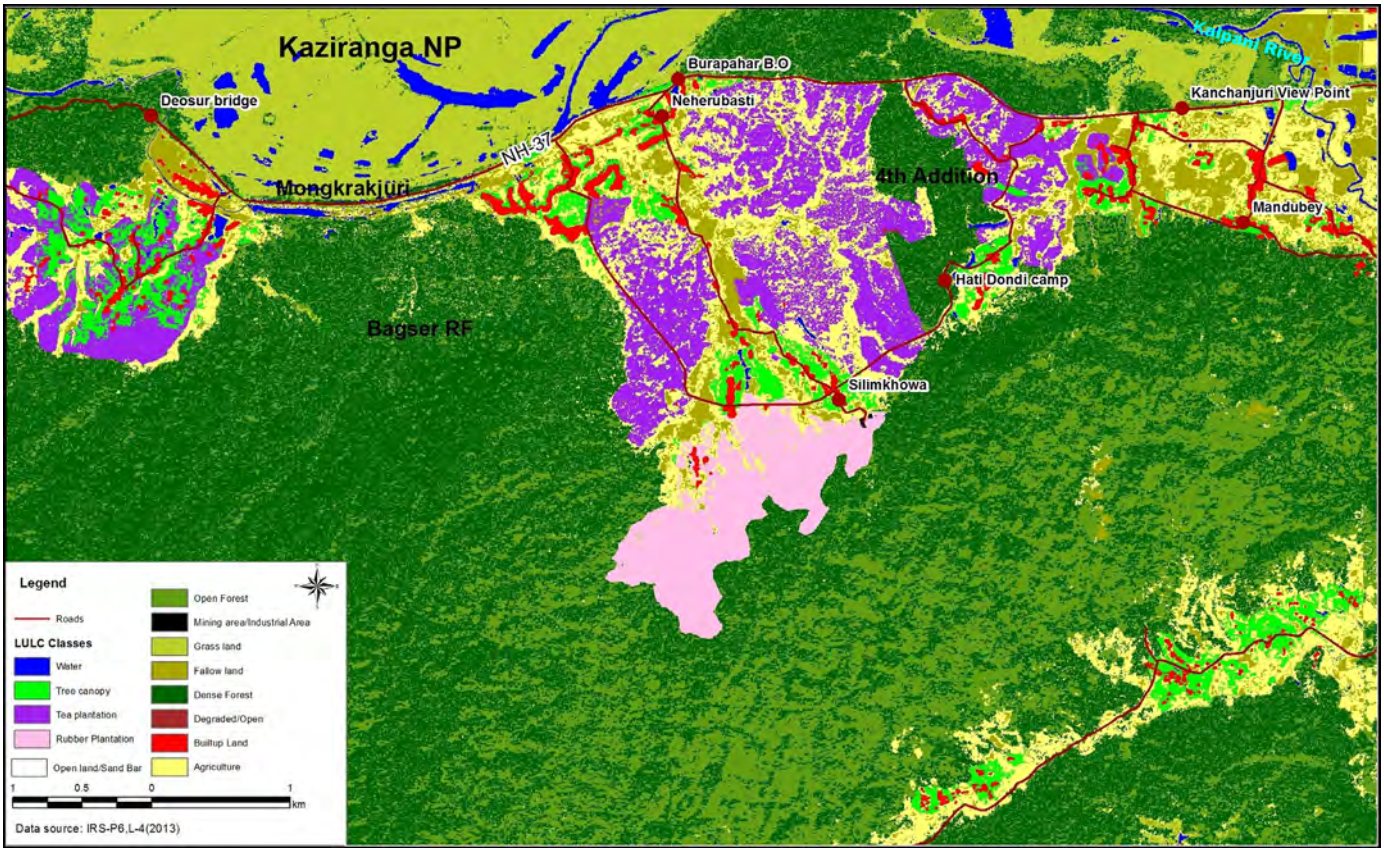

Fig. 9. Mongkrakjuri-Kanchanjuri corridor complex map.

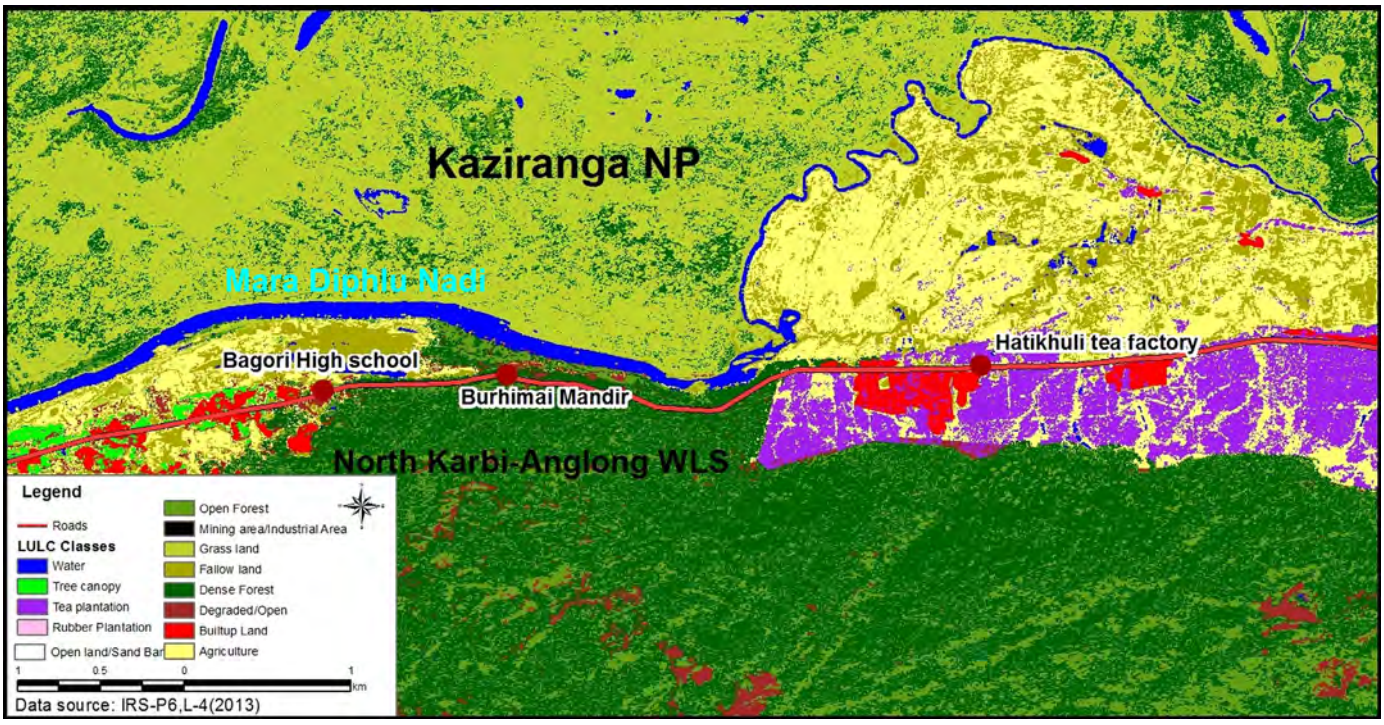

Fig. 10. Haldibari corridor complex map.

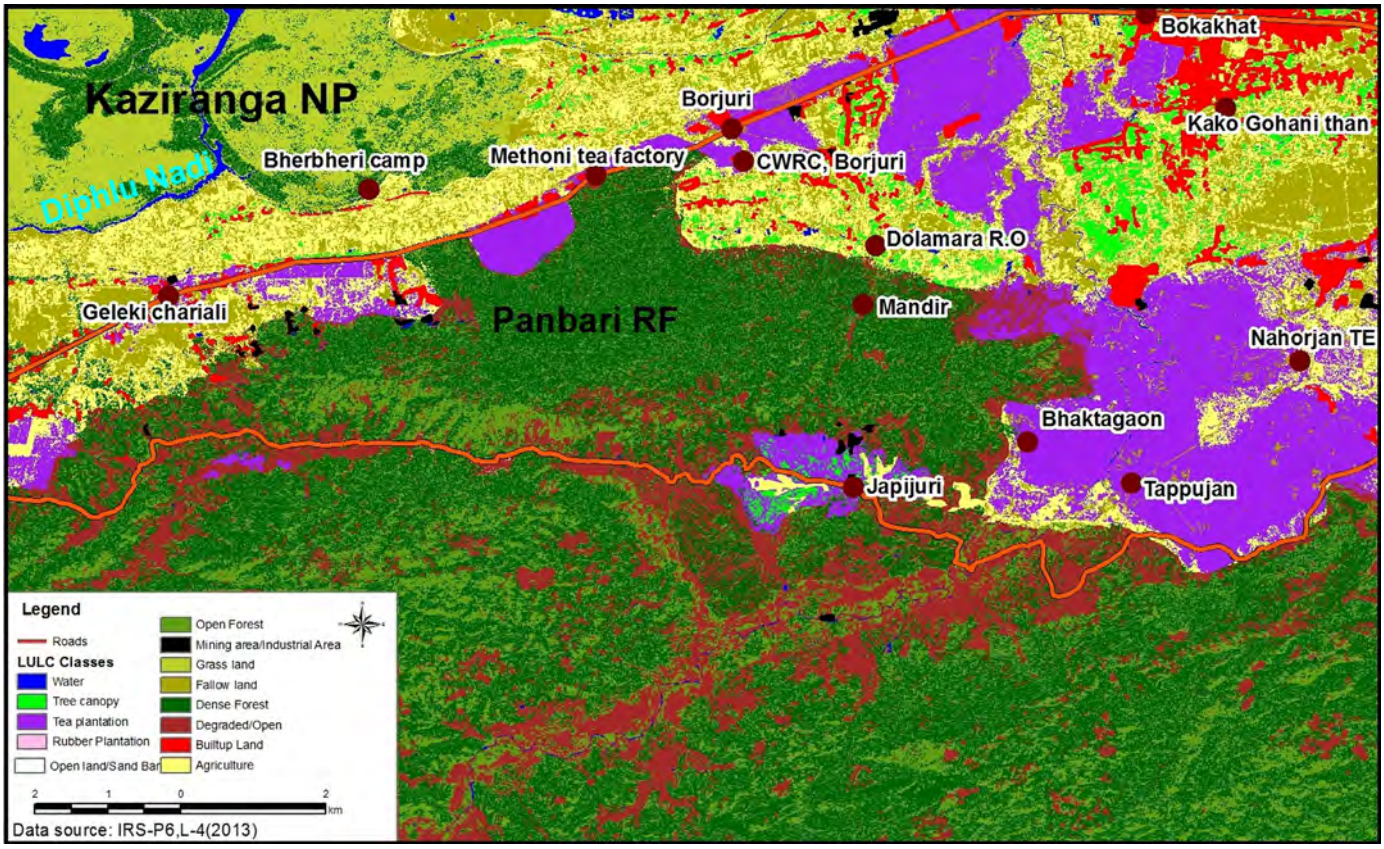

Fig. 11. Panbari corridor complex map.

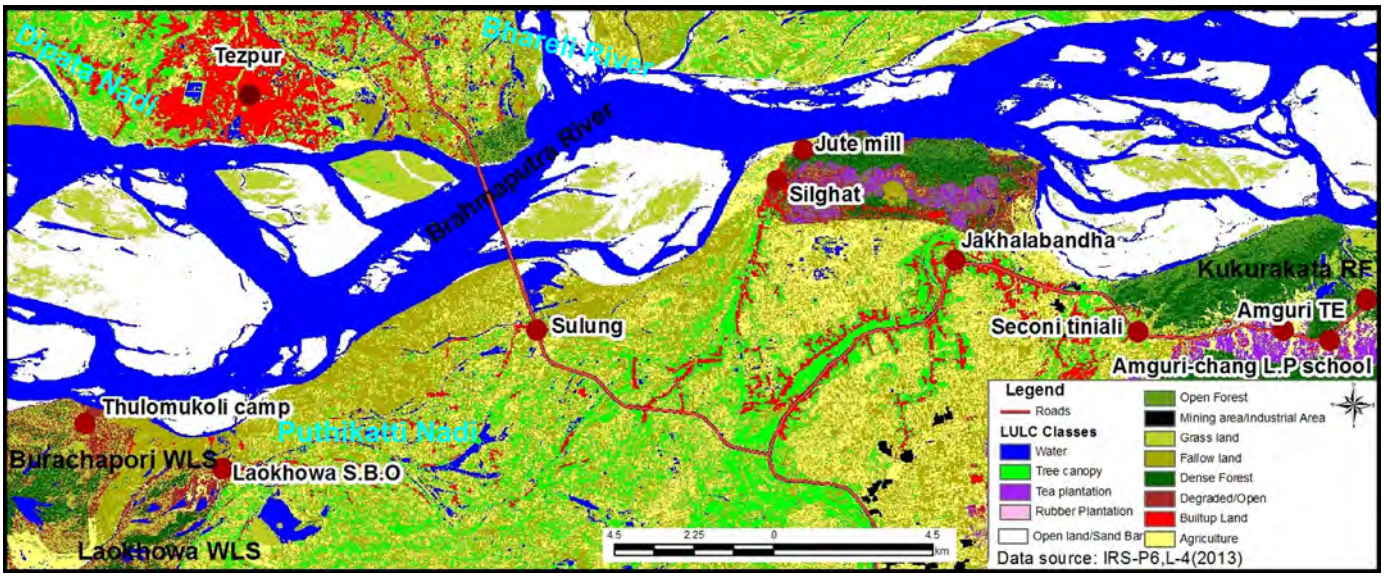

Fig. 12. Kaziranga-Burachapori river corridor complex map.

Total area of this corridor complex has been calculated as 77.57 sq km., and of the total area, 46.8% area is covered by dense forest followed by 13.6% of open forest, 11.5% by tea plantations and 6% by grassland. This complex is significantly affected by anthropogenic pressures as 8.5% land is found to be occupied by agriculture and approximately 2% area was covered by human habitation. Hog deer were found to be actively using the corridor at all hours of the day, followed by wild boars which were slightly more active during late evenings. Rhinos and elephants were found to be using the corridor mainly at night. Other wildlife found to be using the area include barking deers, sambars, wild buffaloes, leopards and tigers. This connectivity is under threat due to conversion of most of the land into agriculture. In spite of growing obstacles and challenges, elephants and other wildlife are still using this area.

4.2.2. The Mongkrakjuri – Kanchanjuri corridor complex

This corridor complex starts from Deosur in the west to Deopani bridge on NH37 to the east. This complex extends between 26° 34′ 49.16″ N and 26° 31′ 32.41″ N latitude and 93° 06′ 20.14″ E and 93° 12′ 07.48″ E longitude. This complex has at least two distinct passages used by wild animals, one at Mongkrakjuri (Deosur) and the other at Kanchanjuri. This complex facilitates animal movement from the western parts of KNP under Bagori range and the 1st addition area in the north to the Bagser RF and southern hilly areas leading to Karbi Anglong in the south. A small stretch for safe passage is offered by the 4th addition area and the Mongkrakjuri connection and this area is still relatively free of disturbance but the remaining parts are mostly under human use and a lot of developments are taking place in the open areas that were previously safely used by animals for their north-south movement. Hog deer and barking deer were found to be actively using the corridor throughout the 24-hour period, followed by wild boars. Sambars and wild buffaloes were found to be more active in late evening. Other large mammals' photo-captured while using the corridors were rhinos, elephants and tigers.

The Mongkrakjuri – Kanchanjuri Corridor complex is spread over 58.2 km^2 area. Of the total area, 41.7% is covered by dense forest followed by open forest (24.2%), fallow land (5.6%) and grassland (8.0%). Important land use categories found in this corridor are agricultural land (9.2%), followed by tea plantation (5.6%), rubber plantation (2.3%) and built up area (1.3%). This indicates that a significant portion of this complex is under human use.

The speeding traffic on NH 37, expansion of human activities including settlements, stone quarries in the hill slopes of Ruthe Pahar, and agricultural practices including monoculture plantation in and around the Mongkrakjuri – Kanchanjuri Corridor are major threats. The mushrooming of private houses and tourist facilities are a major upcoming threat observed during the last few years. There are at least seven old villages or settlement areas in and around this complex and the area is used both by humans and wildlife peacefully even though there are records of sporadic human-wildlife conflicts. The support of these villagers and the communities is still allowing safe passage of wildlife through this complex from the north to the south.

4.2.3. The Haldibari corridor

This corridor starts from the Nagaon – Golaghat boundary in the west to the East Haldibari forest camp on NH 37 to the east. This complex extends between 26° 36′ 15.05″ N and 26° 34′ 2.88″ N latitude and 93° 17′ 58.30″ E and 93° 22′ 19.45″ E longitude. This complex has one clear section used by wild animals near the Burhimai mandir to cross over from the central part of Kaziranga NP in the north to the North Karbi Anglong WLS and other forest areas of Karbi Anglong hills in the south. This corridor section is relatively undisturbed as it is mostly within the boundary of Kaziranga NP. However, along the NH 37, temporary shops and other constructions are slowly growing up close to the temple and is likely to pose a challenge with further growth leading to obstructions.

The Haldibari Corridor is the smallest corridor complex (29.4 km^2) among all the five in this area. Of the total area, 35% area is covered by dense forest followed by open forest (11%) and about 24% area is covered by grassland. Agricultural land is found to be about 13% area and 1.5% are covered by built up area. This corridor is located in the western most part of Golaghat district adjoining the KA hills to the south and Nagaon to the west. In the south, the highway links Kaziranga NP directly to the North Karbi Anglong Wildlife Sanctuary (NKAWLS). The stretch is about 2 km in length along NH 37 located between Bagori and Kohora range offices of KNP. The 5th and 2nd areas added to Kaziranga NP is located to the north of this corridor. In the east, it is bounded by the Hatikhuli tea estate. Hog deer were found to be actively using the corridor throughout the day, followed by wild boars which were slightly more active during the late evening to midnight hours. Rhinos and elephants were found to be more active from late evening till early morning. Other large mammals using the corridor include wild buffaloes, leopards and tigers. Interestingly, a black bear was also photo-captured in the corridor. Villages, religious establishments and speeding traffic on

Table 3
Land use/land cover classes under the corridor complexes in Kaziranga National Park.

Sl. no	Land use/land cover classes	Amguri Corridor Area		Mongkrakjuri-Kanchanjuri Corridor Area		Haldibari Corridor Area		Panbari Corridor Area		Kaziranga-Burachapori River Corridor Area	
		Area in Sq. km	Area in %	Area in Sq. km	Area in %	Area in Sq. km	Area in %	Area in Sq. km	Area in %	Area in Sq. km	Area in %
1	Dense Forest	35.42	46.87	24.28	41.72	10.29	34.99	53.96	32.62	60.23	9.19
2	Open Forest	10.31	13.64	14.11	24.24	3.21	10.93	29.57	17.88	19.8	3.02
3	Tea plantation	8.7	11.52	3.24	5.57	1.35	4.61	18.72	11.32	23.2	3.54
4	Grass land	4.49	5.95	4.71	8.09	6.94	23.62	7.15	4.32	25.01	3.82
5	Agriculture	6.41	8.48	5.38	9.24	3.82	12.99	15.64	9.46	110.23	16.81
6	Fallow land	2.37	3.14	2	3.43	1.82	6.18	10.23	6.19	123.34	18.81
7	Open land/Sand Bar	3.7	4.9	0.14	0.24	0	0	0.1	0.06	83.63	12.76
8	Tree canopy	0.91	1.2	1.53	2.64	0.13	0.45	3.07	1.86	60.82	9.28
9	Water	1.43	1.89	0.72	1.24	0.74	2.52	0.75	0.45	109.54	16.71
10	Built-up area	1.27	1.68	0.77	1.32	0.43	1.46	4.41	2.67	25.03	3.82
11	Mining area	0	0	0	0	0	0	0.38	0.23	1.67	0.26
13	Rubber plantation	0	0	1.3	2.23	0	0	0	0	0	0
14	Degraded/Open	0.55	0.73	0.02	0.03	0.66	2.25	21.42	12.95	13.09	2
Total Area	75.57	100	58.19	100	29.4	100	165.4	100	655.57	100	

the highway are major obstacles for wildlife movement. The speeding traffic on NH-37, expansion of human activities like unplanned settlements, manual stone quarries in the hill slopes of Bagori and agriculture practices around the corridor are major obstacles and threaten the safe movement of animals in this complex. Villages and settlements are mainly situated towards the eastern and western parts of the Haldibari corridor. The eastern part has the infrastructure of Hatikhuli tea estate, markets along the NH-37 and one village at the foothills. On the western part there are at least six settlement areas or villages along the NH-37.

4.2.4. The Panbari corridor complex

This corridor complex starts from the west of the Panbari camp on NH 37 to the Borjuri bridge on NH 37 in the east. This complex extends between 26° 38′ 23.86″ N and 26° 32′ 11.49″ N latitude and 93° 27′ 28.23″ E and 93° 36′ 9.70″ E longitude. This complex has one clear section used by wild animals to cross over from the eastern part of Kaziranga NP to Panbari RF in the south. The animals further move south through this stretch following multiple tracks to reach the Karbi Anglong hills. The area immediately south of Kaziranga NP is comprised of the 3rd addition area which is also a bit disturbed by limited settlements and agricultural activities. The area to the south of Panbari RF towards Dolamara, is disturbed and fragmented and quarry activity is also prominent in this section, thus posing a challenge. The total area of Panbari Corridor complex is calculated as 165 km^2. and of the total area of this corridor complex only 32.6% area was covered by dense forest and 17.9% by the open forest. More than 4% area of this corridor was covered by grassland and about 11.3% area was covered by tea plantation. 10% of this corridor was covered by agriculture land, 13% by degraded land and 11% by fallow land.

This corridor complex mainly falls in the districts of Karbi Anglong and Golaghat. Diffolu and Dadhara rivers coming down from the KA hills pass through KNP before joining the Brahmaputra. It connects KNP through the 3rd addition area in the north to Panbari RF, Dolamara PRF, Haitha Pahar DCRF and the adjoining forest (community owned) of the KA hills in the south. A 4 km stretch of NH-37 runs through the northern most part of this corridor. Barking deer were found to be most actively using the corridor throughout the 24-hour period. Hog deer and sambars were mostly active during the evening and morning hours. Elephants were photo-captured throughout the day and wild boars mostly at night. Other mammals found to be using the corridor includes leopard cats, large Indian civets and leopards. Tea estates, the highway and some villages bordering KNP are regarded as obstructions to free wildlife movement. Tea gardens play a critical role in the Panbari animal corridor complex. The major tea gardens namely Methoni (656.74 hectares), Diffolu (676.37 hectares) and Naharjan (995.35 hectares) with their branches are distributed throughout the area. Moreover, few small-scale tea gardens owned by private and cooperative societies are also growing in the area. Presence of stone quarries and stone crushers within the complex is also an area of concern.

More than 20 villages are found in and around this corridor complex and the villagers are mostly economically weak and mainly depend on agriculture and natural resource extraction for a livelihood. This corridor complex is experiencing various developmental and anthropogenic pressures posing a grave challenge to the safe and free movement of wildlife.

4.2.5. The Kaziranga – Burachapori river corridor

This corridor complex stretches from the Kukrakata RF in the western part of Kaziranga NP to the Burachapori WLS, the nearest wildlife habitat to the west along the river Brahmaputra. This complex extends between 26° 39′ 23.92″ N and 26° 28′ 58.09″ N latitude and 92° 44′ 03.12″ E and 93° 04′ 57.34″ E longitude and covers an area of about 655 km^2. This river corridor facilitates movement of wild animals along river banks, multiple riverine channels and islands (*chars*). This complex also provides further linkages to Orang NP and beyond for movement of animals to the west through the river Brahmaputra and its banks. The

Table 4
Forest fragmentation classes (2002–2013).

Forest fragmentation Classes	2002		2013	
	Area (Sq. Km)	Area (%)	Area (Sq. Km)	Area (%)
Patch	10.35	0.86	50.23	6.09
Edge	8.52	0.71	22.40	2.72
Perforated	1.66	0.14	3.18	0.39
Core	1176.69	98.28	748.28	90.80
Total	1197.23	100.00	824.09	100.00

areas in between the river channel is relatively undisturbed. However, the areas along both the banks are quite disturbed and is under intensive human use hampering any likely free movement of wildlife.

This corridor complex is the largest and covers about 655 km^2. This complex is also the most disturbed as only 9% area was covered by dense forest, 3% by open forest, 3% by tea plantation and 3% by grassland. A large area of this corridor complex is under human activity as about 17% area was covered by agriculture, 3.8% by built up area and 2% by degraded land and mining area. This complex is also having the presence of a large number of settlements including around 4% of built-up land.

4.3. Forest fragmentation

Fragmentation analysis was carried out for the study area for the years 2002 and 2013. Figs. 13 and 14 and tables 4-5 depicts the results of the fragmentation analysis. There was an increase in the area covered by patch forest from 10.35 sq.km. in 2002 to 50.23 sq.km. in 2013. There was increase in edge forest which was 8.52 sq.km. in 2002 to 22.40 sq.km. in 2013. An increase in area covered by perforated forest was also observed from 1.66 sq.km in 2002 to 3.18 sq.km in 2013. There was a spontaneous decrease in core forest from 1176.69 sq.km in 2002 to 748.28 sq.km in 2013. The core forests identified in the complexes has been experiencing a high rate of fragmentation. This is mainly due to the increase in developmental activities in the study area. The NH-37 which runs on the south of the Kaziranga National Park has become a zone of escalating developmental activities for the local population as well as the tourists. The traffic on the highway has also increased several folds. There are corridors for animal movement, come of which have become almost non-functional due to anthropogenic activities. Perforated forest showed an increase in areas that depicts more of the core forest areas has been degraded continuously and converted in perforated areas. The edge area also increased thereby degrading the perforated areas into more edge forest, the patch areas also seems to be increased. The overall change shows the fragmentation is more pronounced in the core forest areas and more areas are getting transformed into different land use classes due to various anthropogenic pressures that has severely disturbed the environmental balance. Fragmentation of forest therefore forms an important study in this region because it results as a threat to the existing biodiversity as the reserve forests consists of diverse richness in plant and animal species. Also, there was a spontaneous increase in the number of patches as well i.e., from 878 in 2002 to 6473 in 2013.

5. Conclusion and policy recommendation

Northeast India has been facing a depletion of forest cover at an alarming rate resulting in the destruction of more than 1000 km^2 of forests annually, consequently leading to increase in the incidents of human-elephant conflict recently in Assam (Das et al., 2012). Elephants are severely under threat as they engage in intense conflict with humans in the Golaghat district of Assam; the forests of Golaghat and nearby district of Karbi-Anglong facilitate the elephants with a key landscape for their habitats represented by seven Reserve Forests (Das et al., 2012). Fragmentation of forest patches has seriously impacted the elephant population of the area; also, tea gardens are increasing in the area causing depletion of the forest cover, this encroachment has led to a hike in the intensity of conflict in the area (Das et al., 2012).

Mapping reveals that these corridor complexes of Kaziranga which offer passages for the movement of animals are not secured patches of connected forests but are mostly areas with multiple usage. These corridor complexes facilitating the connectivity for wildlife movement mostly between the habitats of Kaziranga and forests in the hills of Karbi Anglong to the south are rapidly losing its openness factor in the face of growth in anthropogenic and developmental activities, hampering the free movement of wild animals. The indigenous people with their traditional lifestyle and subsistence economy are the champions who have helped in conserving wildlife, especially the rhinos, to flourish in the park. They have mostly preserved the natural richness of the area and has lived in harmony with the wildlife of the area allowing the secured movement of these animals and co-existing with them since ages. However, with the influx of new people, increasing population pressure and globalization leading to a change in lifestyle and aspirations in the area, the traditional and sustainable lifestyle is getting affected by the modern values of life and development. The fallout of fast-paced development affecting the region and changing human values are quite evident as also indicated by the spread of occurrence of human-wildlife interactions at times resulting in conflict in these complexes. An increase in vehicular traffic and better roads have also led to many road kills during the last few years hampering the safe use of these corridor complexes by wildlife. The involvement of local communities in preserving and protecting wildlife habitats and corridor complexes is crucial, especially for peaceful co-existence. The forest department, other line departments of the Government of Assam along with NGOs such as WWF-India, WTI, Aaranyak and others are working collaboratively and actively to ensure safe use of these corridor complexes and protection of the same by working with all major stakeholders and by actively engaging with the communities in the area for their continued support.

We have prepared the depositional and erosional surfaces within the study area boundary (Fig. 15) to understand its relation between the degradation in vegetation cover and animal movements. There is a significant proportion of area that qualifies as erosional surface. Soil erosion in the long run deteriorates the soil quality and change in land use types also plays a significant role in this increased rate of soil erosion (Tsegaye, 2019; Dhali et al., 2020). This is in turn degrades the forest and other vegetation of a particular area as nutrient value of soil would be reduced. It is also evident from the statistics as there was a drastic increase in the area covered by degraded forest in 2013 as compared to that in the year 2002. The rapidly growing anthropogenic pressures have led to a declining availability of cultivable land and has caused a very high rate of soil erosion. Most of the northern part of Kaziranga National Park are badly affected by the river bank erosion each year and its cause to the loss of animal habitat. Landscape vulnerability (Sahana et al., 2015a) to flood inundation is one of the important factors of forest degradation and habitat loss in the study area. Riparian Strip Quality Index (RSQI) assessment can be help to understand the riparian quality of the study area in different part of the national park and its relation with the monsoonal floods and riverbank erosion (Novoa et al., 2018; Saha et al., 2020). Kaziranga is the have the world largest habitat for Greater one-horned rhinos (Rhinoceros unicornis) and maximum of these population are sits in the southern bank of Brahmaputra River. But this area is very vulnerable to several natural hazards like river bank erosion and seasonal inundation due to monsoon floods. Each year during the peak of monsoon flood 95% of Kaziranga national park was underwater (up to a depth of 4.5 m), causing massive disturbance to the wild animals in this national park (Tribune, 2016).

The long-term management plan for these corridor complexes include a land use zonation plan, enforcement and regular monitoring. These complexes which facilitate peaceful co-use by wildlife and humans may cease to provide a suitable form in the days ahead. The few functional wildlife passages and corridors that presently exist across NH-37 between the park and the adjoining hills of Karbi Anglong have

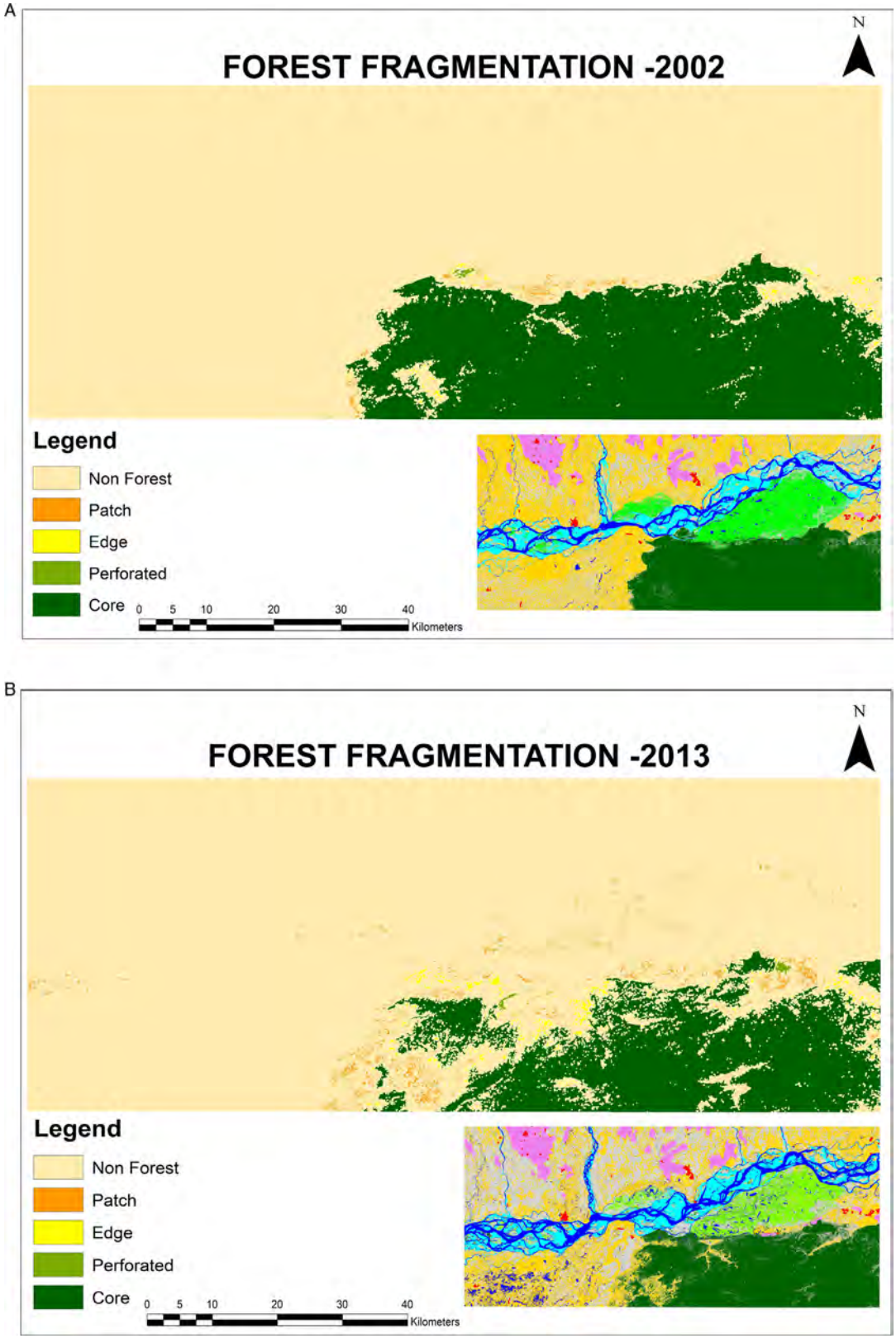

Fig. 13. Forest fragmentation map 2002 (A) and 2013 (B).

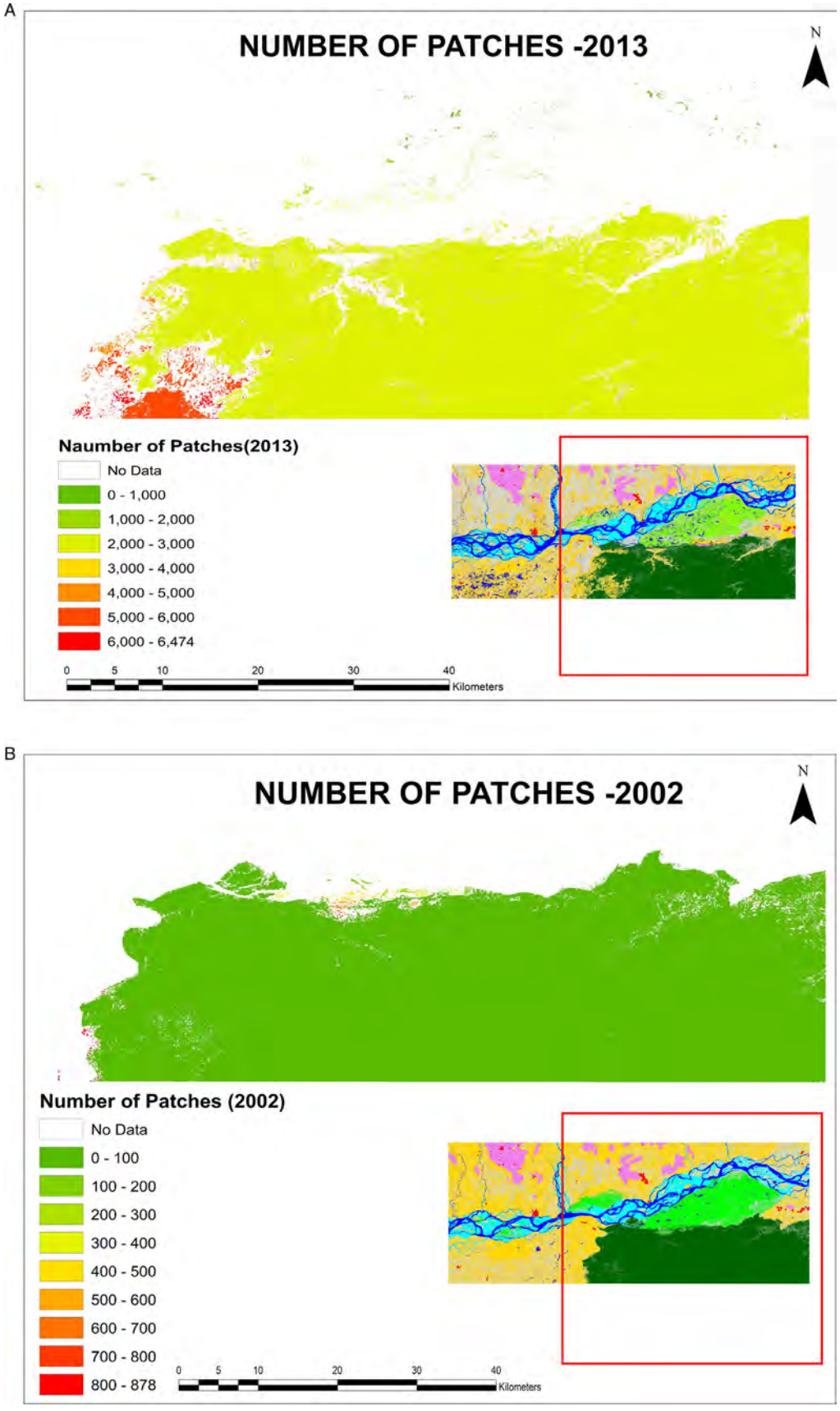

Fig. 14. Number of Patches in the study area 2002 (A) and 2013 (B).

Table 5
Landscape fragmentation classes (2002–2013).

Fragst at classes		Year	
		2002	2013
Total (Class) Area in Hectares	CA	134,995.78	120,009.94
Percentage of Landscape	PLAND	19.17	17.05
Number of Patch	NP	878.00	6473.00
Patch Density (Number per Hectares)	PD	0.16	1.34
Largest Patch Index (Percent)	LPI	18.92	16.14
Total Edge (Meters)	TE	3,132,792.00	9,403,108.00
Edge Density (Meters per Hectare)	ED	4.45	13.36
Landscape Shape Index	LSI	21.31	67.85
Area Mean (Hecatares)	Area_MN	120.75	12.74
Area Range (Hecatares)	Area_RA	133,231.42	113,632.36
Shape Mean	Shape_MN	1.25	1.19
Shape Range	Shape_RA	16.16	44.65
Clumpiness Index	CLUMPY	0.98	0.94
Patch Cohesion Index	COHESION	99.94	99.91
Aggrestion Index	AI	98.56	94.98

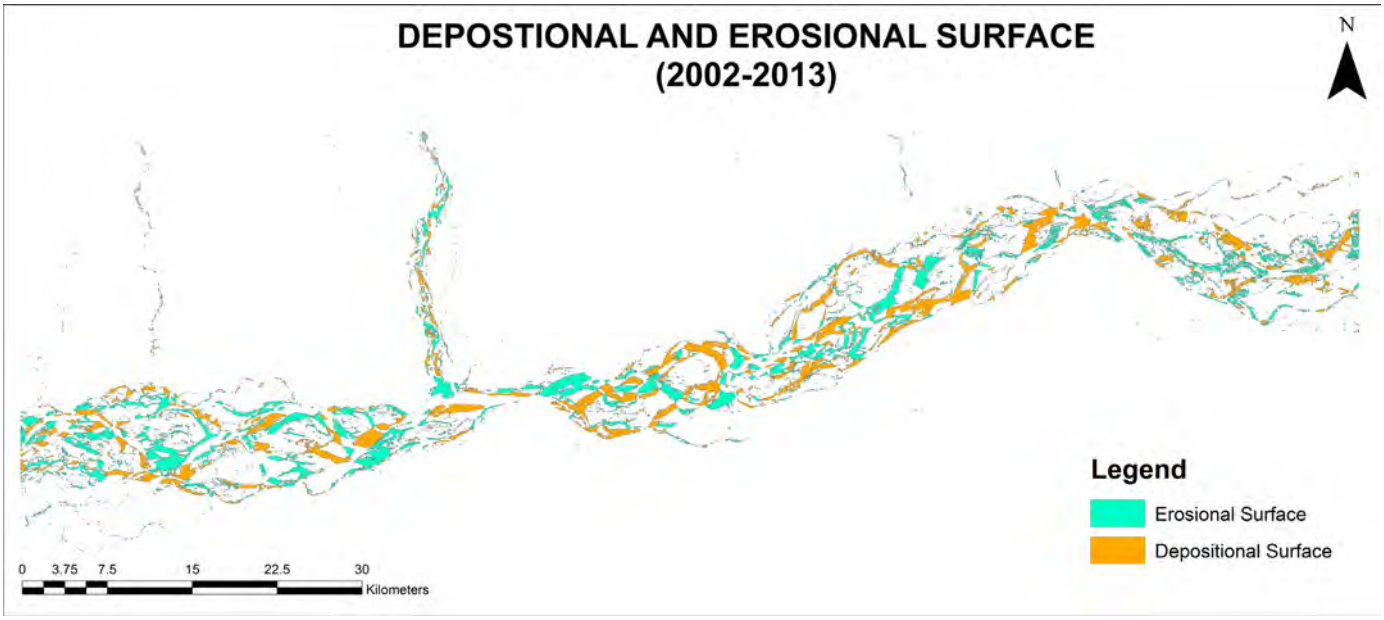

Fig. 15. Depositional/erosional surfaces (2002 - 2013) within the study boundary and its relation between the degradation in vegetation cover and animal movements.

been subject to increasing anthropogenic pressures and there needs to be proper interventions at the earliest. The indigenous people settled in and around these complexes should be identified and provided space to contribute towards conservation and be also made the guardians of the wildlife, their habitats and corridors for a secured Kaziranga NP.

The much-trumpeted conservation success of Kaziranga due to the increasing number of rhinos, elephants and tigers could be a dangerous indicator. The unusual increase and concentration of these animals in a single protected area with limited space and connectivity could be harmful in the long run. It might be that, because of loss of secured habitats in the surrounding areas, the wildlife has flocked into the safer and rich habitats of Kaziranga NP. The future success and viability of Kaziranga ecosystem is highly dependent on the preservation of the corridor complexes and adjoining forest patches, especially in the Karbi Anglong hills and the entire landscape needs to be managed as a single conservation unit. Based on observations during the field and from the land use land cover analysis of the corridor premises, the present paper gives the following recommendations to secure the corridors complexes:

1 Eco-sensitive zones identified, need to be notified and ecotourism/homestead tourism promoted for the benefit of the fringe villages. Additional protection camps should be identified properly and established in strategic locations. Underpasses at strategic points across the highway for free movement of animals and strict restriction of unplanned developmental activities need to be established. Awareness among villagers and local communities on the importance of the corridor and wildlife conservation should be increased.
2 Proper land use zonation with a demarcation of a No Development Zone around the corridor area should be done to prevent and stop further conversion of the habitat. Monitoring and regulation of developmental activities that could cause further degradation/conversion of the wildlife habitat should be enforced. Efforts on building a positive relationship with the communities through engagement activities like mass awareness, health camps, and implementation of Human-Animal Conflict (HAC) management strategy should be promoted.
3 Preparation of flood susceptibility map (Sahana et al., 2015b; Sahana and Patel 2019) and identify the flood prone areas with

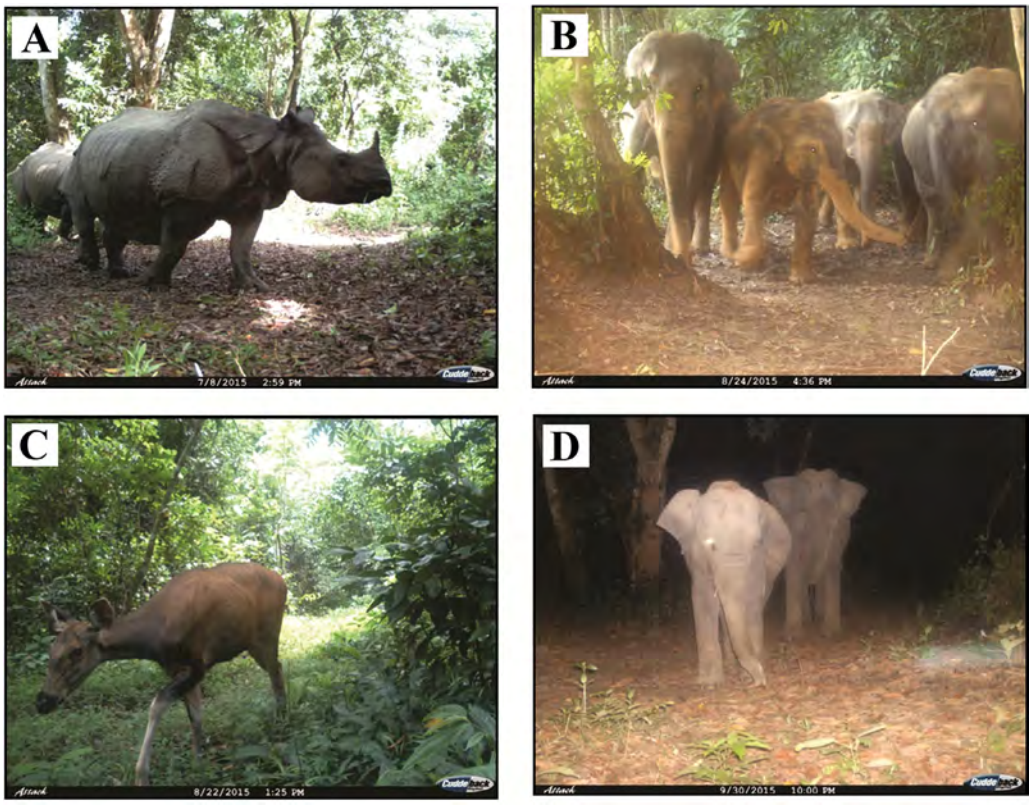

Plate 1. (A) Rhinos using the Haldibari corridor (Photo – WWF India), (B) Elephants using the Kanchanjuri corridor (Photo – WWF India), (C) Deers using the Kanchanjuri corridor (Photo – WWF India), (D) Elephants using the Haldibari corridor (Photo – WWF India).

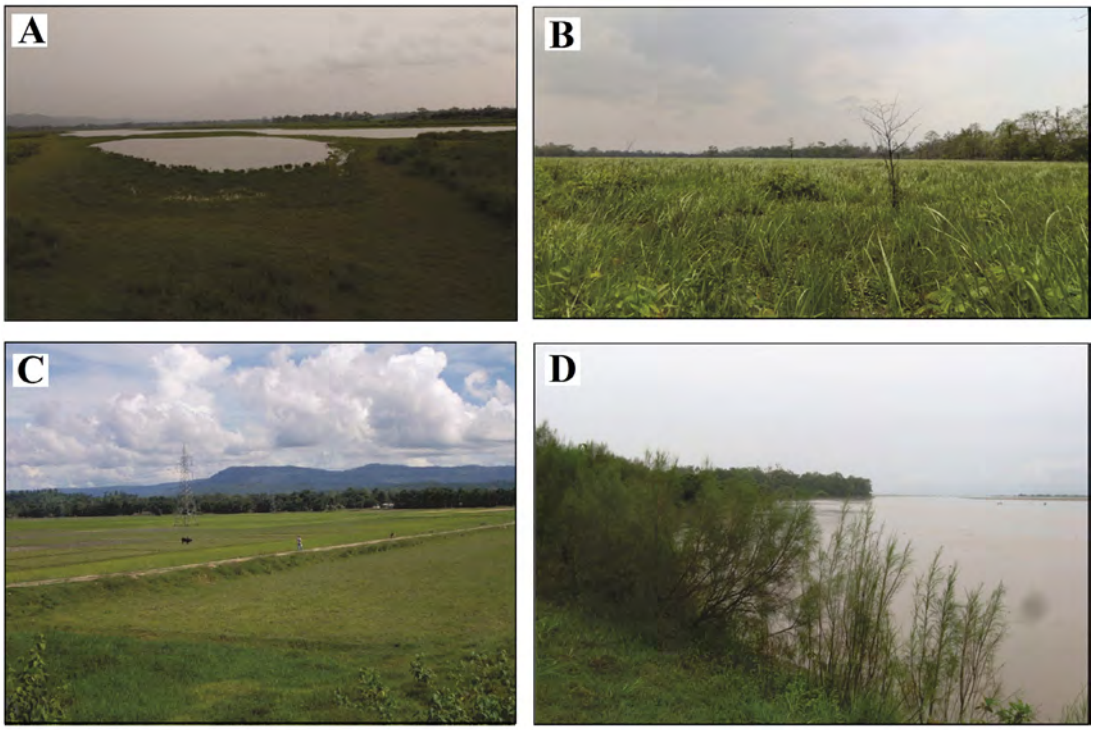

Plate 2. (A) Wetlands inside Kaziranga NP (Photo – Amit Sharma), (B) Grasslands inside Kaziranga NP (Photo – Tridip Sarma), (C) Agriculture fields adjoining Kaziranga NP (Photo – Amit Sharma), (D) Wetlands inside Kaziranga NP (Photo – Amit Sharma).

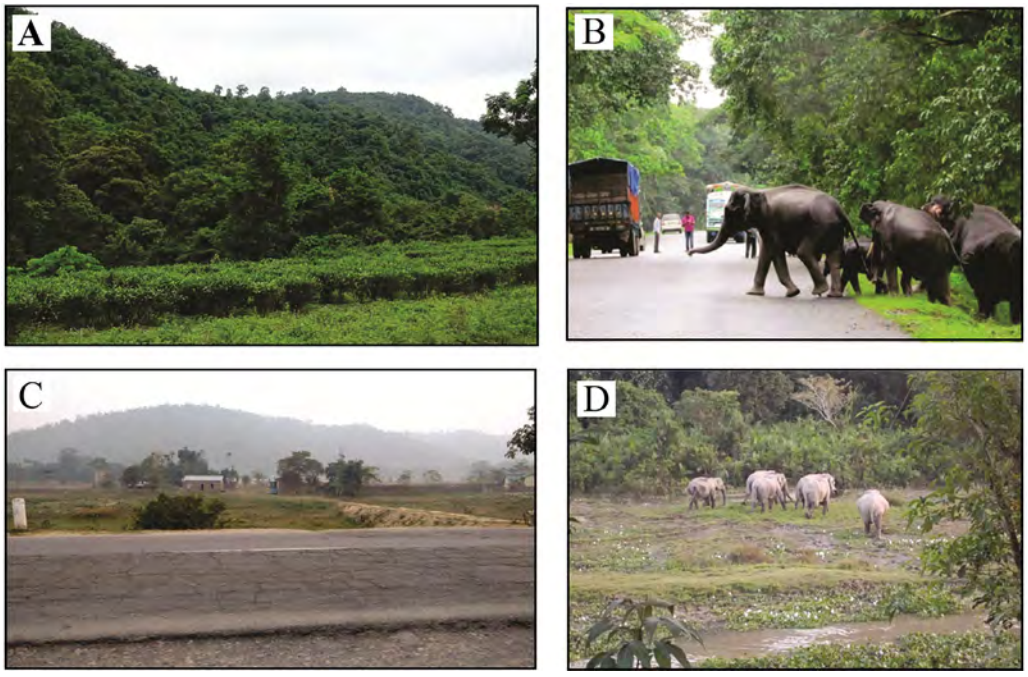

Plate 3. (A) Tea and Forest in the Kanchanjuri corridor area (Photo – Tridip Sarma), (B) Elephants moving across NH37 during daytime (Photo – Rathin Barman); (C) A snapshot of the Kanchanjuri corridor south of NH37 (Photo – P.J. Bora); (D) Elephants crossing over from Kaziranga to use the habitats in Bagser RF south of NH37 (Photo – Amit Sharma).

the corridor complexes can be help to mitigate the animal movement problem during the monsoon time and its need to link the proper land use zonation and needs to be designed and implemented in consultation with all stakeholders.

4 Further development and expansion of tea garden activities needs to be monitored and regulated. Stone quarries/creasers/collection centres need to be checked.

5 Developing community-based conservation program by documenting the socio-economic status and traditional knowledge system of the local communities should be explored.

The time frame, database and methodology adopted in the study are very effective for the present study to understand the patterns of land cover change and forest fragmentation and its relation with the wildlife movement in the corridor complexes of Kaziranga National Park, India, yet there are few limitations of the study. The study can be further improved with the ecological quality of the riparian corridors can be assessed using the Riparian Strip Quality Index (RSQI). Another improvement can possible to demarcated flooded extents along the Brahmaputra and identify the flood vulnerable areas which can help to monitor wild animal and local level planning. However, species distribution modelling and leas coast methods analysis for Corridor Mapping can also provide further insights the present study area Plates 1–3. Lastly this is a very dynamic landscape with continuous changes triggered by the river Brahmaputra and its tributaries as well as various developments affecting the movement of wildlife as such it is much more necessary to conduct similar studies at regular intervals for a better conservation of the area.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Acknowledgements

We are grateful to *Mr. Ravi Singh*, CEO & Secretary General, WWF-India, *Dr Sejal Worah*, Programme Director, WWF-India and *Dr Dipankar Ghose*, Director, Species, WWF-India for their support to the project. We are also thankful to *Mr. Sarkam Rongphar, Mr Hiten Baishya, Ms. Pallavi Chakraborty, Mr Tridip Sarma* and *Mr. Jayanta Deka* (NBL &KKL team members), WWF-India, for their valuable inputs in the course of the project work. We also express our sincere thanks to the GIS team of IGCMC Division, WWF-India, for their continuous support and help in carrying out then the work. We would also like to express our thanks to Mr M.K. Yadava, Director Kaziranga NP for his support, advice and encouragement to conduct this study.

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