Recent trends of forest cover change and ecosystem services in eastern upland region of Bangladesh

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ABSTRACT

Forest cover changes have diverse outcomes for the livelihoods of rural people across the developing world. However, these outcomes are poorly characterized across varying landscapes. This study examined forest cover changes, associated drivers, and impacts on ecosystem services supporting livelihoods in three distinct areas (i.e. remote, intermediate and on-road) in the Chittagong Hill Tracts region of Bangladesh. The three zones had features of decreasing distance to major roads, decreasing levels of forest cover, and increasing levels of agricultural change. Data was collected from satellite images for 1989-2014, structured household interviews, and group discussions using Participatory Rural Appraisal approaches with local communities to integrate and contrast local people's perceptions of forest cover and ecosystem service change with commonly used methods for mapping forest dynamics. Satellite image analysis showed a net gain of forest areas from 1989-2003 followed by a net loss from 2003-2014. The gain was slightly higher in intermediate (1.68 percent) and on-road (1.33 percent) zones than in the remote (0.5 percent) zone. By contrast, almost 90 percent of households perceived severe forest loss and 75 percent of respondents observed concomitant declines in the availability of fuel wood, construction materials, wild foods, and fresh water. People also reported traveling further from the household to harvest forest products. The main drivers of forest loss identified included increased harvesting of timber and fuel wood over time in the intermediate and on-road zones, whereas swidden farming persisted as the major driver of change over time in the remote zone. The contrast between remotely-sensed forest gains and household-perceived forest loss shows community experiences may be a critical addition to satellite imagery analysis by revealing the livelihood outcomes linked to patterns of forest loss and gain. Community experiences may also evoke solutions by characterizing local drivers of forest change. Failing to disaggregate the impacts of forest loss and gains on ecosystems services over time may lead to uninformed management and further negative consequences for human well-being.

Key words: *Forest loss and gain; ecosystem services; livelihoods; drivers of forest cover change; plantations; households; landscape*

Highlights

- Forest cover changes were assessed by using satellite imagery and local people's perceptions
- Drivers of forest cover changes shift over time and space in the landscape
- Rural households perceived a severe decline in ecosystem services and forest cover
- Households identified small forest gains in planted tree cover, which they perceived to have limited impact on improved ecosystem service

1. Introduction

Forest loss and land degradation has increased significantly across tropical countries with consequences for biodiversity (Wright, 2005) and human well-being (Alfonso et al., 2016). Though the global rate of deforestation has decreased in the past decade, the loss of natural forests still continues at an alarming rate in many countries of South America and Africa (FAO, 2015a). Forest cover changes have diverse implications, mainly negative effects on the sustainable supply of ecosystem services from small to large spatial scales (Balthazar et al., 2015, Sunderland et al., 2017, Ellison et al., 2017). In tropical forests in particular, most of the impacts of forest loss are clearly evident at the local scale in the livelihoods of rural people who depend on forests and trees to support their livelihoods (Gray et al., 2015). Ecosystem services are broadly defined as benefits that people obtain from ecosystems following MA (2005), and have been recognised for local livelihoods (Fisher et al., 2013). There are a variety of benefits that ecosystems provide, mainly provisioning, regulating, cultural, and supporting services to human well-being. Changes in ecosystem affect many aspects of human well-being, but in particular, people who often directly depend on services including food, fresh water, fuel wood are the most vulnerable to changes in ecosystems.

Studies led by Sunderland et al. (2017) across a forest transition gradient in six tropical landscapes showed a close association between forest loss and fewer ecosystem services available than in the past. The loss of forest areas corresponds to variations in fuel wood, wild foods, fodder for livestock along different locations of a landscape. On the other hand, forest gain referred to by several studies as increase in intensive management of timber production and conversion of native forests into monoculture plantations may result in trade-offs, especially with water purification and regulation, nutrient cycling, soil maintenance, genetic diversity maintenance, recreation, and possibly cultural values (Pirard et al., 2016, Balthazar et al., 2015, Alfonso et al., 2016, D' Amato et al., 2017).

Forest loss generally results from a combination of direct causes (e.g. agriculture expansion) and underlying forces (e.g. institutional, economic) (Kanninen et al., 2007). Agricultural expansion is by far the most prevalent land-use change associated with forest cover loss, along with infrastructure development and wood extraction (Geist and Lambin, 2002). Typically, smallholder subsistence agriculture is viewed as a less significant driver of forest loss than industrial agriculture, road development, or national policies favouring in-migration and incentives to encroachment in forests (Heinimann et al., 2017, van Vliet et al., 2012). Further, secure land tenure reduces forest cover loss across a range of ownership regimes and drivers (Robinson et al., 2014). However such widely-acknowledged causes and underlying forces interact in multiple and complex ways, making our understanding of drivers of forest loss at local levels incomplete (Brown and Schreckenberg, 1998). There are place specificities, multiple sectors (e.g. forest, agriculture, mining and infrastructure), cross-scale aspects (local, sub-national and national), and tenure conditions associated with forest cover changes at the local level (Bong et al., 2016). Therefore understanding the diversity of possible causes and underlying forces of forest change requires not only broader regional and historical perspectives (Lambin et al., 2003), but also local perspectives, which provide context and a frame of reference from within a landscape (Shriar, 2014).

Global patterns of tree cover reflect large scale changes from deforestation to reforestation across a range of natural processes and human interventions including planted forests (Rudel et al., 2016, Sloan and Sayer, 2015). However, the loss of forests followed by regrowth of tree covers or monoculture plantations can have low-level outcomes for livelihoods and ecosystem services in the landscapes depending on who gains the benefits and who bears the costs (Lindström et al., 2012, Barbier et al., 2010). Declining forest area associated with an expansion of commercial agricultural area as well as economic development can lead to the irreversible impacts on the delivery of ecosystem services and thus impoverishment of local people. As such, a recovery in forest cover due to plantation forestry implies environmental degradation has raised growing debate in the context of sustainable forest management and human well-being (Alfonso et al., 2016, Ferraz et al., 2014).

Until recently, studies of forest cover change provided a partial understanding of the changes without addressing the impacts on ecosystem services. Based on spatial analysis and community perception, studies showed the dynamic trend in recent forest area change (Twongyirwe et al., 2015, Twongyirwe et al., 2017) or partly drivers (Rudel et al., 2016, Hosonuma et al., 2012). But these have not addressed associated impacts of forest cover change on ecosystem services supporting local livelihoods. A few studies highlighting local communities' experience of forest cover change have shown livelihood impacts in terms of changing accessibility and availability of ecosystem services (Ehara et al., 2016, Thanichanon et al., 2013). But these also lack explaining the roles of forest cover dynamics for both gain and loss in the livelihoods of local people. Such lack of an integrated assessment of remotely-sensed deforestation measurements in combination with perceptions and livelihood impacts has undermined a proper understanding of how forest changes reflect local experiences and livelihoods over time and space. Perceptions about the forest changes reflect community views towards the benefits available in the past and the roles of existing management in sustaining ecosystem services (Alfonso et al., 2016). Integrating community experiences ultimately provides options for overcoming trade-offs and enhancing synergies between forest management and improvement of rural livelihoods (Fisher and Hirsch, 2008) and well-being (Yang et al., 2015).

Within the context of limited integration of remote sensing data and local perspectives for understanding forest change and drivers, the objective of this study was to analyse forest cover change, associated drivers and assess the subsequent impacts on the ecosystem services supporting livelihoods of rural people in the eastern Chittagong Hill Tracts (CHT) region of Bangladesh. Forests and trees historically contributed to the livelihoods of indigenous people in CHT region due to demand for a range of provisioning services (wild food, fuel wood, medicine and water) as well as the source of national revenue through harvesting of raw materials for wood processing, paper and pulp industries. Though forest uses have an important role in the livelihoods of people living in the region (Miah et al. 2012), over-exploitation and degradation that commenced during the last century (Rasul, 2007) and continue to the present have implications for sustaining the benefits (Rasul, 2009). Deforestation may have effects on the ecosystem services provided by forests such as decline of direct benefits of wild food, fuel wood, construction materials, and biodiversity while it has indirect contributions to the loss of soil fertility, degradation of fresh water sources and emission of carbon. Furthermore, expansion of tree cover with monoculture plantations might also threaten soil protection or fresh water flows due to lower undergrowth and natural vegetation (Hossain 2003). Changes in availability of any of the ecosystem services can profoundly affect livelihood security to the prevalence and persistence of poverty.

There have been no evidence-based studies undertaken for the region to understand how people perceive the forest cover change and how this change affects the ecosystem services that are important for their livelihoods. Existing studies have identified the roles of forest products including fuel wood, bamboo and wild foods in rural livelihoods (Miah et al., 2012, Misbahuzzaman and Smith-Hall, 2015) or economic values of agroforestry over swidden farming for sustainable land uses (Rahman et al., 2016, Rasul and Thapa, 2006). Limited spatial information and community perspectives on forest and tree cover changes begets a lack of understanding of the actual trends and patterns of ecosystem services affected in the landscape. To achieve the broad objective in the study, we asked specific questions: 1) how has forest cover changed over the time and space in the landscape?; 2) do the underlying drivers vary over the time and space?; 3) what are the perceptions of local people towards forest cover change and trends in availability of ecosystem services?; 4) and what are the implications of local perceptions on understanding of forest cover change for sustainable management?. The paper recognises the ecosystem services that people perceive to be important to achieve their livelihoods. Moreover it considers understanding the factors that cause ecosystem services to change is essential to design interventions that can have positive benefits.

2. Materials and methods

2.1. Study area

The CHT region is distinct from the rest of Bangladesh in terms of biophysical, social and economic characteristics. Located in the south-eastern upland region of the country, CHT covers approximately 1.3 million hectare, 8% of the total land area and nearly 40% of the total forest area in Bangladesh (BFD, 2017). The biophysical characteristics of the region include diverse hills slopes, valleys and plains and ancient formations of largely igneous rock in the Hindu Kush Himalayas (Khan et al., 2012). The region's key land cover is pre-dominantly forests or grasslands, farming areas, and watersheds (Khan et al., 2007). Twelve ethnic groups inhabit the region (UNDP, 2009) and have historically been dependent on natural resources, mainly forest and agriculture primarily swidden farming. However, since the beginning of the 1980s the CHT region has experienced a steady increase in population causing enormous pressures on forest ecosystems and their associated benefits to support local livelihoods and watersheds (Ahammad and Stacey, 2016).

The harvest of timber was widespread in the CHT region from the early 1700's until the end of 19^{th} century (Rasul, 2007). Currently unlogged forest covers approximately 72,000 ha or only 15–20% of the total forestlands in the region. The remaining area is largely secondary forest with mixed natural and planted tree communities (i.e. a mix of naturally regenerating bamboo and planted timber species) and monoculture planted forests. Planted forests are mainly dominated by Teak-*Tectona grandis* and Gamar-*Gmelina arborea* species. The majority of the primary forests declined in area between 1700 and 1800, although there is no accurate historical information available on forest cover changes for that period. Limited information on CHT for the periods 1960–80 and 1990–2005 show that natural forest cover declined during this time (FAO, 2015b). Though a clear estimate is not available, during 1970-1990, forest loss exceeded approximately 77,000 ha (FAO, 2015b) of valuable trees of regenerating capacity in natural forests (i.e. Garjan–

Dipterocarpaceae spp) throughout the region (Khan et al., 2012). Data on historical changes in Kassalong and Rankhiang, the two major reserves in the region, show that in 1963, natural forest covered 172,000 ha, but declined to 84,000 ha in 1990 and to 70,000 ha in 2005 (FAO, 2015b).

Deforestation is higher in CHT compared to other forested areas of Bangladesh (Reddy et al., 2016), although areas of monoculture plantations have increased or remained stable since the 1990s. Broadly, the underlying reasons for deforestation in the region are often considered to be agricultural systems (swidden farming) (Kibria et al., 2015, Rahman et al., 2011) and institutional arrangements (Thapa and Rasul, 2006). National policy has focused on logging to supply the wood industries and supported intensive plantation programs with monoculture species (mainly Teak and Gamar). As a result, a gradual loss of trees, either for revenue generation (Rasul, 2007) or through illegal felling and clearing/burning practices (Rahman et al., 2011), has resulted in an increase in area of non-forestlands. By contrast, teak-based, smallholder economic activities with different fruit plants in swidden farming lands have continued to expand tree cover. However the distinct outcomes of forest loss and gain may have distinct outcomes for rural communities in terms of availability of different forest-based ecosystem services.

2.2. Data collection and analysis

2.2.1. Approach to study site selection

To examine broad patterns of forest change and livelihood impacts, we selected the villages in three different zones (Figure 1) with regard to particular criteria such as population density, agriculture modifications, proximity to natural forests, markets and roads following the methodology described by Sunderland et al. (2017). During a scoping study, we consulted local government respondents, interviewed villagers, reviewed existing reports and literature to classify the landscape into the three zones (i.e. remote, intermediate and on-road) following these criteria

(Ahammad and Stacey, 2016). Remote zone was characterised with the presence of subsistence farming, higher reliance on natural forest and distant locations from market. Intermediate zone comprised a mixed of subsistence and commercial agriculture including monoculture trees and better access to road or market. The on-road zone represented the area with large monoculture of trees and crops, little natural forests, but better communications to market and urban centers.

Finally each zone included four villages (in total 12 villages) with relatively different forest and agriculture systems, types of forest and management from the next (Table 1). In each village, 304 households were selected randomly for surveys on their perceptions of forest cover change and associated ecosystem services.

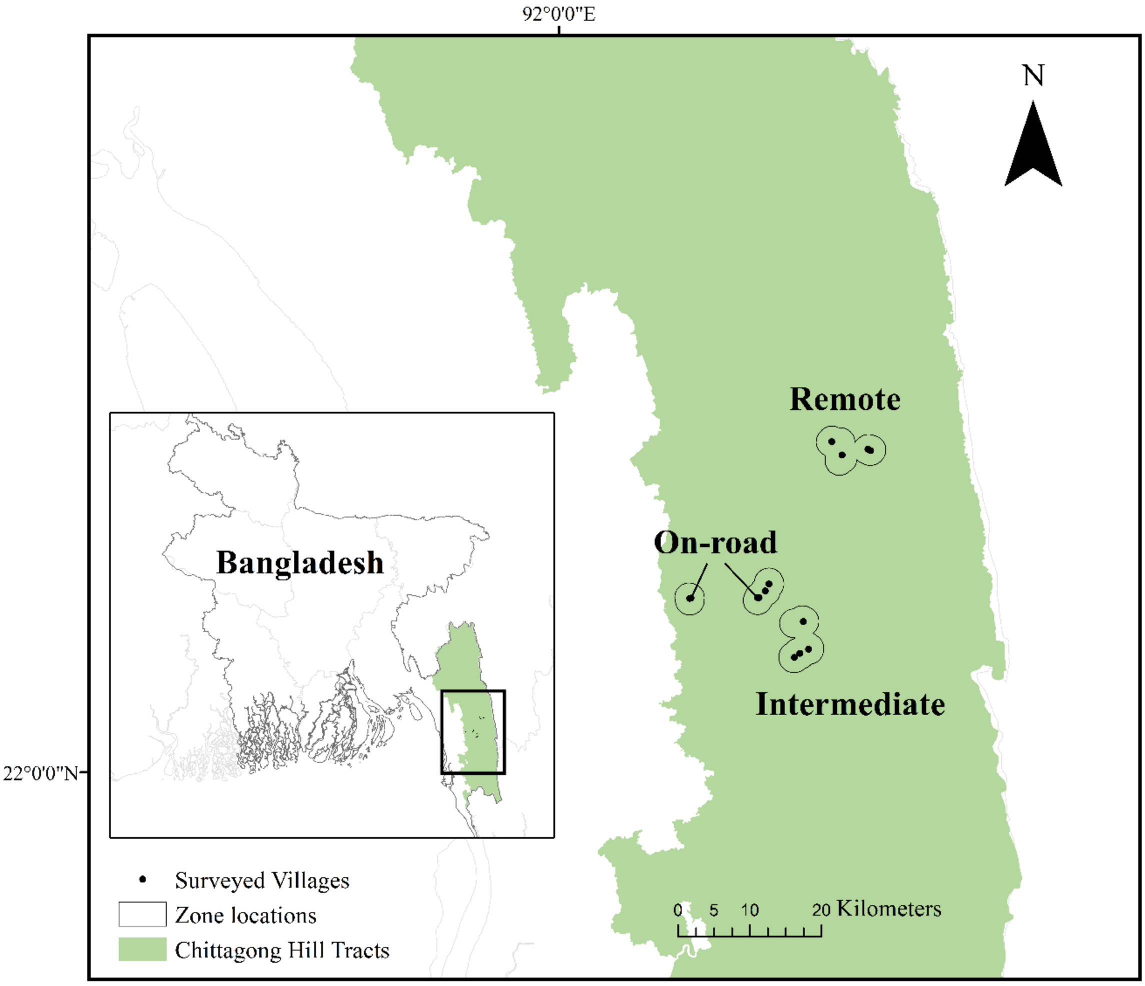

Figure 1: Study locations in Chittagong Hill Tracts region of Bangladesh

Table 1: Salient features of three zones in Chittagong Hill Tracts of Bangladesh (Ahammad and Stacey, 2016)

	Remote	Intermediate	On-road
Population density (persons/sq. km.)	38 nos.	62 nos.	176 nos.

	Remote	Intermediate	On-road
Elevation/altitudes (meters above sea level)	100-350	70-172	50-90
Age of villages (settlement years)	25-30	30-50	>50
Main economic activities	Subsistence farming, forest product harvesting and trade, day labour	Farming, forest product harvesting and trade, fruit-tree gardening, day labour and employment	Farming, day labour, forest trade, employment, small business, land rent
Forest types (ecological)	Secondary forests (tropical evergreen and semi-evergreen); Plantation	Mixture of forest types: mostly secondary forests with small natural forest, industrial and private plantation	Mostly industrial and private plantation
Forest management	State owned forest reserve (Rhainkhyong reserve and Kaptai national park)	State and private plantations and community owned forest reserve	State and private plantations
Distance to forests (km) from the villages	<0.5	0.5-5	>5
Distance to sub-district/district market (km/time)	80 km/2-3 hours travel by boat	45 km/0.5-1 hour by motorbike	5 km/30 minutes by motorbike

2.2.2. Mapping of forest cover change

Forest cover in the CHT region was mapped using composites of 30-metre Landsat imagery from three years, 1989, 2003, and 2014. The landscape is best described as a matrix of forest (forest cover exceeded 80% of the landscape in each year), with narrower and more numerous non-forest patches. For example, the 2014 mean patch size of non-forest ranged from 0.9-1.2 ha across the three zones. Cloud cover masks were generated for every image using band thresholds applied with ENVI image analysis software (ENVI 5.0, 2012). Then training sites were delineated for four land cover classes: tree cover, non-tree vegetation (crops, home gardens, fallow), inundated areas, and non-vegetated surfaces (bare soil, built areas), identified from GPS data collected in the field. The training sites for the 1989 and 2003 composites were supplemented with sites identified using the historical Google Earth image archive, as most field data were unlikely to be representative of past land cover. Historical images were used only if they were sufficiently high resolution to identify land cover and acquired within one year of the 1989 and 2003 composite image acquisition dates. Maximum Likelihood Supervised Classifications were constructed from Landsat bands 1-7 as well as the Normalized Difference Vegetation Index and Normalized Burn Ratio. Inundated areas and cloud cover were combined into a single no data class and excluded from further analysis, while non-forest classes were ultimately combined. Accuracy of the land cover maps was assessed for the 2003 and 2014 classifications, using both field data collected during 2013 and 2014, and data sampled from high resolution Digital Globe imagery acquired within a 1-year window of the Landsat classification dates. Overall map accuracy was 79% for 2014 and 83% for 2003 (Table 2). The land cover classification was unable to differentiate between natural and teak plantations using Landsat imagery. Classification error was generally attributable to two factors: the small size of fields and difficulty in accurately classifying juvenile plantation forests, mainly Teak (*Tectona grandis*). Generally, newly established plantations were mapped as non-forest but were classified more accurately as they aged.

Table 2: Classification accuracy of 2014 Bangladesh land cover map

	Field data set				
	Land cover	Non-Forest	Forest	Total	User's accuracy
	Forest	6	41	47	87%
2014	Non-forest	43	17	60	72%
Land cover	Total	49	58	107	
	Producer's accuracy	88%	71%		Total 79%
	Forest	8	58	66	88%
2003	Non-forest	42	12	54	78%
Land cover	Total	50	70	120	
	Producer's accuracy	84%	83%		Total 83%

2.2.2.1. Defining zone boundaries and quantifying forest cover change

To determine the boundaries of each zone, we collected GPS points of each household location. Individual households were buffered by 2 km, which ensured no overlap in buffers between households in remote, intermediate, and on-road zones. Two kilometres also reflected the maximum distance of locally important forest reserves and plantations identified by key informants in our scoping study (Ahammad and Stacey, 2016). These 2 km buffers were then merged by zone, which resulted in three separate zone areas (Remote-43.9 km^2, Intermediate-43.1 km^2, and On-road-39.6 km^2). Due to the large distance between villages characterized as "on-road”, our area for the on-road zone is not contiguous. Total forest cover and non-forest cover within these areas were analysed from 1989 to 2003 to 2014. The transition of individual Landsat derived 30 meter pixels in these zone areas were also characterized as stable forest, forest gain, dynamic forest, forest loss, or stable non-forest (Figure 2). We also quantified net forest cover at each timeframe and net annual rate of forest change to characterize overall dynamics seen for each zone.

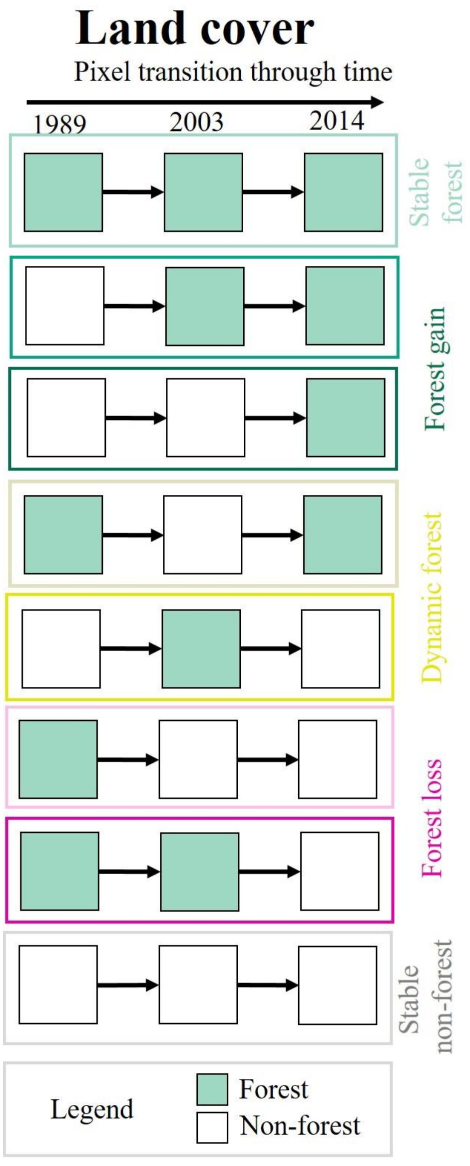

Figure 2: Transitions of forests over time. Green squares indicate forest pixels, while white squares show non-forest pixels through time. Pixels were defined as stable forest if they remained

forested from 1989-2014. Pixels were classified as forest gain if they reforested in 2003 and remain forest or reforested in 2014. Pixels that switched cover types in 2003 were deemed dynamic forest. Pixels that changed from forest to non-forest in 2003 and remained non-forest in 2014, as well as pixels that changed to non-forest in 2014 were defined as forest loss. Stable non-forest included pixels that remained non-forest from 1989-2014.

2.2.3. Household surveys

Household surveys provided the people's perception on the change of individual ecosystem services such as wild foods, fuel wood, construction raw materials and water, including variation and change in their availability and change in travel time to access these ecosystem services. Interviews with structured questionnaires were conducted at 304 households across 12 villages in three zones. We asked the respondents three questions: 1) what have you observed on forest cover around your village over the last 30 years; 2) how the forest cover changes affected the availability of ecosystem services to your households?, and 3) how forest cover changes affected the travel time and distance to gather forest and tree products. During interviews, we did not use the term ecosystem service with the respondents across the twelve villages. Rather we explained it to the respondents as the benefits on the availability of important ecosystem services in their livelihoods and their perceptions concerning those. The perceived changes at households were recorded from the structured responses of the respondents as "increased", "decreased", or "stayed the same" towards the forest area; the availability and types of forest-based ecosystem services that they perceived as affected and their direct impacts on livelihoods (i.e. travel distance to gather forest products).

Descriptive statistics mainly frequency distribution was run with the IBM SPSS 23 software to calculate the numbers of the responses to the questions within the households. Then we quantified the proportions of the respondents for overall surveyed samples and difference across the three zones. A chi-square test of independence was conducted to show the association of any affected ecosystem service perceived by the households with the zones. Furthermore, post-hoc tests was performed to reveal the significant (significance level at α=0.05) association of particular ecosystem service changes with specific zones.

2.2.4. Participatory Rural Appraisal (PRA)

PRA combines approaches and methods that enables local people (rural and urban) to share their knowledge of life and situations for making a plan of actions (Chambers, 1994). PRA techniques have now become widely accepted tools in conservation and development research (Malleson et al., 2008), and in combination with surveys, provide a more complete understanding of the diversity of rural livelihoods (Ellis, 2000) affected by forest cover changes. The participatory approaches used here supplement household surveys and historical analysis of forest over the time (Chambers, 1994).

Trend analysis is a PRA method/tool that account people's experiences on the changes in land use and cropping patterns around their community, the causes of changes and trends (Chambers, 1994). It is applied through an exercise with a group of local people to capture information on forest cover change in a particular year around the villages, associated drivers, and key threatened ecosystem services over the period 1989-2014. Information collected during trend analysis with local communities (Kumar, 2002) provided insights on the historical process of forest cover changes, associated drivers of forest change, as well as allowing us for identification of which ecosystem services were perceived to be the most affected by this forest change.

The tool was conducted in six villages (two from each zone). Two villages in each zone were selected due to the similar ethnicity of the communities and physical locations (Supplementary material). In each of the six villages, five-to-six participants (total 25 male and 11 female) included elderly (knowledgeable); forest users who were frequent visitors for collection of products and farmers. During the trend analysis, we asked the participants “how they observed the forest cover change around their settlement over their years of residence”. The discussion on forest cover change considered both loss and gain over time. The information gathered was grouped in two different time categories (years of high forest cover and years of low forest cover). The drivers of forest cover change for particular years were also identified in each zone.

To elucidate the livelihood impacts of forest cover changes, we asked the respondents “what are the forest-based ecosystem services that they consider as important and the most affected”. It was intended to lead discussions among the group participants and draw an agreed view on the types of forest ecosystem services affected and their underlying causes. Across the six villages, the participants agreed on fuel wood, construction materials, wild food and water were severely impacted with forest cover changes. They considered the services as the most important to support day to day livelihoods and the changes in the supply of the services. Content analysis was done to elicit the information on forest cover changes and related drivers from the discussion.

3. Results

3.1. Spatial analysis of forest cover change

Figure 3 (A-B) shows the trend of forest cover change in three zones (i.e. remote, intermediate and on-road) of the landscape during 1989-2014. Based on satellite image analysis, it was evident that changes in forest cover varied over time and space. In the three zones, there was a net gain of forest areas from 1989 and 2003 but a net loss from 2003-2014. Forest gain was comparatively higher in the intermediate zone and on-road zone than in the remote zone. From 1989-2003, the forest area increased from 72.1% to 91.2% and 70.6% to 85% in intermediate and on-road zones respectively (Figure 3.b), while there was a small increase in forest from 84.1% to 90.3% in the remote zone.

From 1989-2003, remote, intermediate, and on-road zones showed a total increase in forest cover (Figure 4) with a net annual increase of forest of 0.5 %, 1.68 %, and 1.33 % respectively. A net annual decrease of forest was found for all zones from 2003 onwards. This loss was slightly higher for intermediate (0.67%) and on-road zone (0.67%) than for the remote (0.33 %). Overall the forest area change follows a similar pattern across the zones, though the increase and decrease over the time was slightly higher in intermediate and on-road zones than for remote.

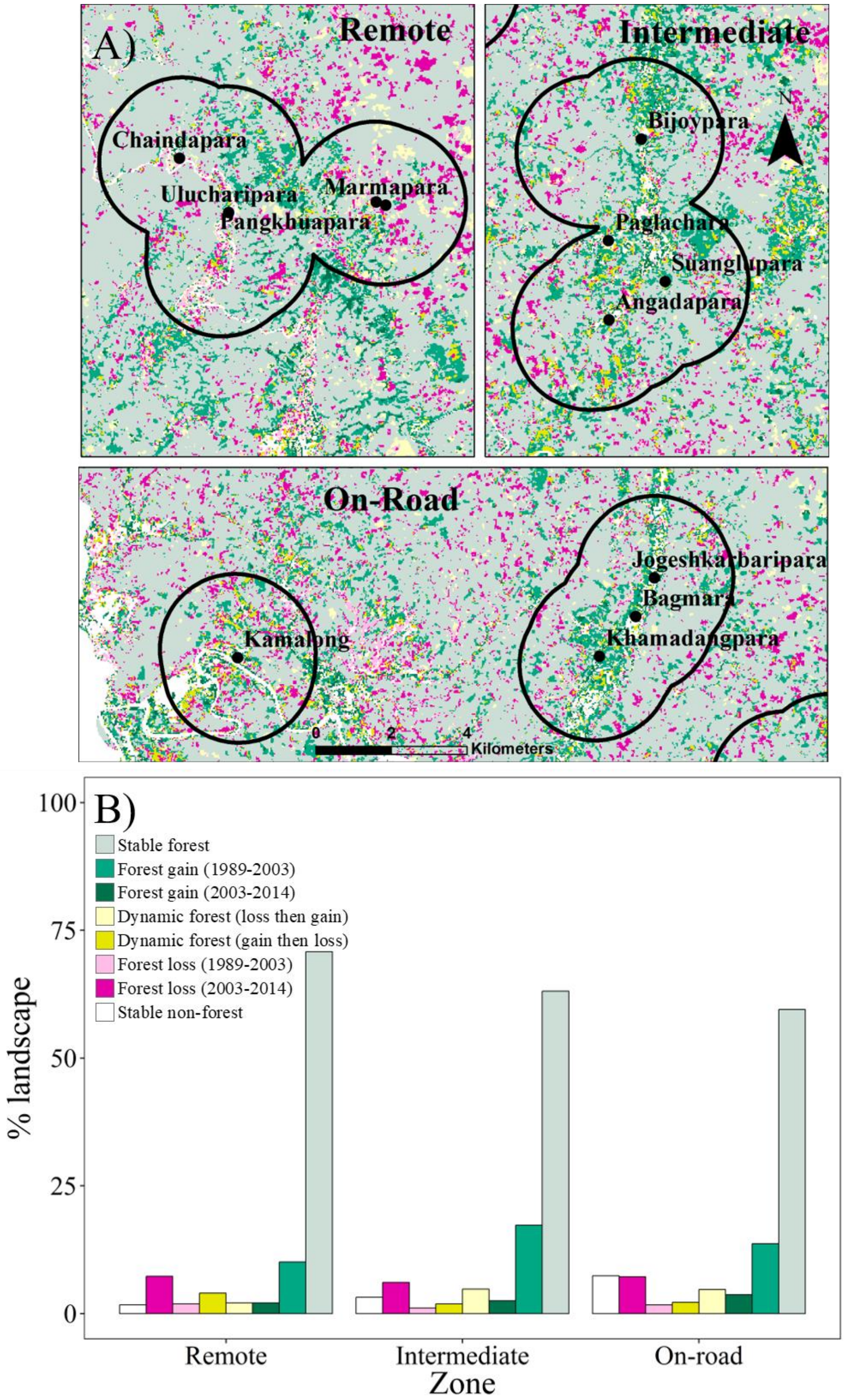

Figure 3: Forest cover change over time and space: A) forest cover change between 1989-2003 and 2003-2014 across the zones; B) forest cover change percent of landscape

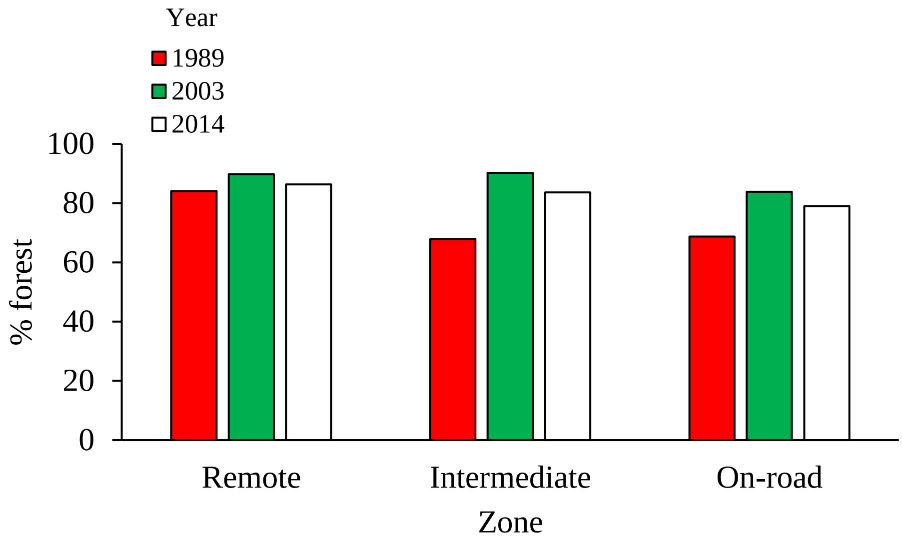

Figure 4: Annual proportions of forest area (%) across zones

3.2. Perceptions of forest cover change and drivers

Compared to the findings of satellite imagery, the household surveys on forest cover changes revealed a different trend. Though the satellite image shows both forest gain and loss, the respondents in the surveyed households perceived more loss of forest areas over the time across the landscape. It was evident that 90% household respondents perceived a decline of forest and tree cover around them. Among the three zones, more households (96%) in remote area perceived higher levels of forest loss compared to 89% households in intermediate and on-road zones (Figure 5). Respondents reported a slight increase of forest cover due to the monoculture plantation in both intermediate and on-road zones.

During the trend analysis exercise, the loss of forest cover was typically noted by the participants as a decline in natural forest, while the perceived gain was a result of plantation expansion. It was found that villages in remote locations have close proximity to forest reserves where more surveyed households perceived a loss of forests.

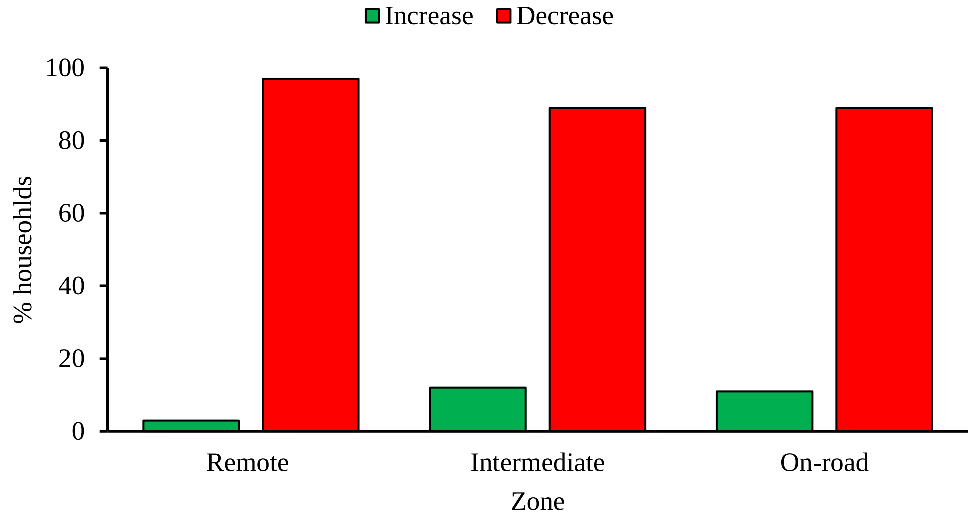

Figure 5: Proportions of households (percentage) perceived forest cover changes at three zones

The PRA trend analysis exercise revealed the main drivers of forest cover change in all three zones were extraction of timber and non-timber forest products (i.e. particularly fuel wood and bamboo), shifts in agricultural practices from swidden agriculture to monocultures of trees, market and insecure tenure (Table 3). Harvesting of forest products has been identified to have strong influence on the forest area loss across the zones. Relatively, both domestic and commercial harvesting of timber and non-timber forest products affected forest loss more in the intermediate and on-road zones. In the remote location, participants reported the domestic use of fuel wood contributes to the loss of tree cover along with illegal logging.

Though forest loss from 2003-2014 seems to be relatively minor, participants perceived that forest loss continued with road development and increasing market for timber, bamboo and fuel wood. Subsistence agriculture, mainly swidden farming, has influenced forest clearing across the zones. While swidden agriculture declined in recent decades in the intermediate and on-road areas, it remained an important driver of forest change over both timeframes in the remote location. The results of the household survey also showed high levels of forest loss associated with land clearing for annual swidden farming. It was the most significant driver reported by the respondents in the remote location. The participants in remote location reported higher land clearing ether on natural forest patches or fallow lands near the forest though it was less observed along intermediate and on-road zones respectively.

Table 3: Relative contributions of drivers to forest loss identified by the local communities for the period of 1989-2003 and 2003-2014

	Drivers	Weight (%)	Drivers	Weight (%)
	Period		Period	
Zones	1989-2003		2003-2014	
Remote	Swidden farming	40	Swidden farming	30
	Timber and fuel wood extraction (domestic usage)	45	Timber and fuel wood extraction (domestic usage)	45
	Insecure tenure	15	Insecure tenure	25
Intermediate	Timber and fuel wood extraction	60	Timber and fuel wood extraction	65
	Swidden farming	30	Swidden farming	20
	Road and market development	5	Road and market development	10
	Insecure tenure	5	Insecure tenure	5
On-road	Timber and fuel wood extraction	75	Timber and fuel wood extraction	55
	Swidden farming	15	Swidden farming	15
	Road and market	10	Road and market	30

3.3. Perceptions of changes in ecosystem services

Forest cover change has affected the ecosystem services identified by the household respondents from all villages surveyed as important for their livelihoods. During the PRA exercise with community, four ecosystem services (construction materials, fuel wood, wild food, and fresh water) were identified as both highly impacted by forest change. Overall, 90% households surveyed in all villages experienced a decline in availability of forest ecosystem services (i.e. fuel wood, wild food, construction materials and fresh water mainly) associated with the forest loss (Figure 6). A higher proportion of households in the on-road zone (95%) reported lower availability of the forest products than intermediate (89%) and remote (84%) zones. As such, households also spent more time and travelled further distances to gather forest products. Eighty-two percent of households spend more time gathering forest products compared to the time they started settlement over 20 years. Relatively, households in remote (87%) and on-road zones (88%) were affected more by these changes than households in the intermediate zone (71%). Only 18% of households surveyed in the intermediate zone have not experienced changes in the travel time and distance to gather forest products.

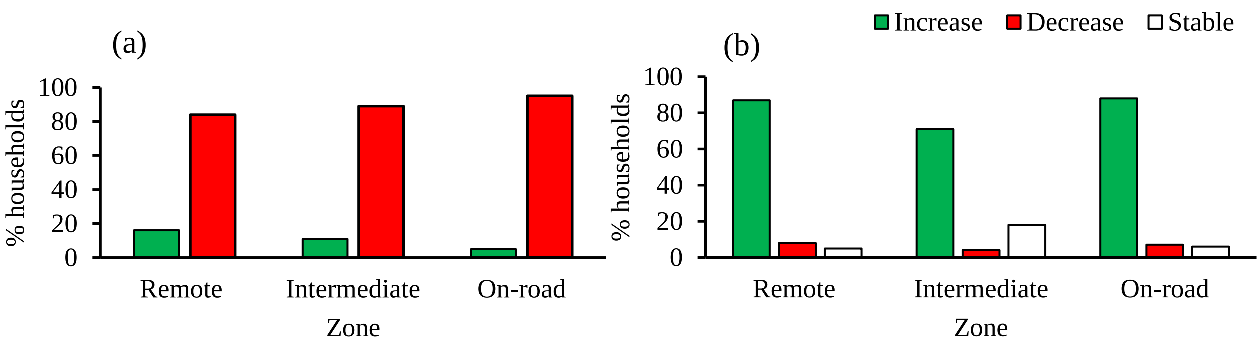

Figure 6: Perceived availability of forest-based ecosystem services (a) and travel required to access forest ecosystem services (b) across three zones.

Figure 7 presents household experiences on specific forest ecosystem services over the period of time since their establishment. Many households reported a shortage of construction materials (85%), fuel wood (78%), and wild food (73%). Sixty-four percent of households surveyed reported that fresh water availability decreased or that their sources of fresh water were affected by loss of natural forests, while 36 % of the respondents reported that access to fresh water increased or improved availability of sources. Over a quarter of households also reported no changes in the availability of forest-sourced foods. Only 16% households did not face any shortages in fuel wood for their own consumption over the time.

Our results show variations in the perceived changes for particular forest based ecosystem services held by households at the zone level. A chi-square test of independence showed an overall association of the changes in construction materials perceived by the households with the zone level (X^2=14.85; $p<0.05$). However the subsequent post-hoc test conducted showed no significant difference among the zones for particular changes (i.e. increase, decrease or stable) of construction materials. Overall the availability of construction materials declined for households. But more households reported their supply of construction materials remained stable in the remote zone (16%) than in the intermediate (9%) and the on-road (5%) zones (Figure 7). Ten percent of households in the on-road zone reported that the availability of construction materials increased, while less than 5% households in intermediate and just above 1% in remote villages reported an increase in the availability of construction material.

Fuel wood was the second most affected service found with a significant difference at the zones levels (X^2=53.73; p<0.05). High proportions of households in intermediate (86%) and on-road (84%) zones experiencing declines compared to the remote area (61%). The post-hoc test showed a significant association of fuel wood with the remote zone (X^2=20.25; p<0.05). Fuel wood supply for 38% of households remained stable in the remote zone was also observed significant (X^2=46.24; p<0.05) though no households in the villages reported an increase in fuelwood. Increases in fuel wood supply only observed in the on-road zone, as reported by 11% households showed a significant association (X^2=16; p<0.05) with this location.

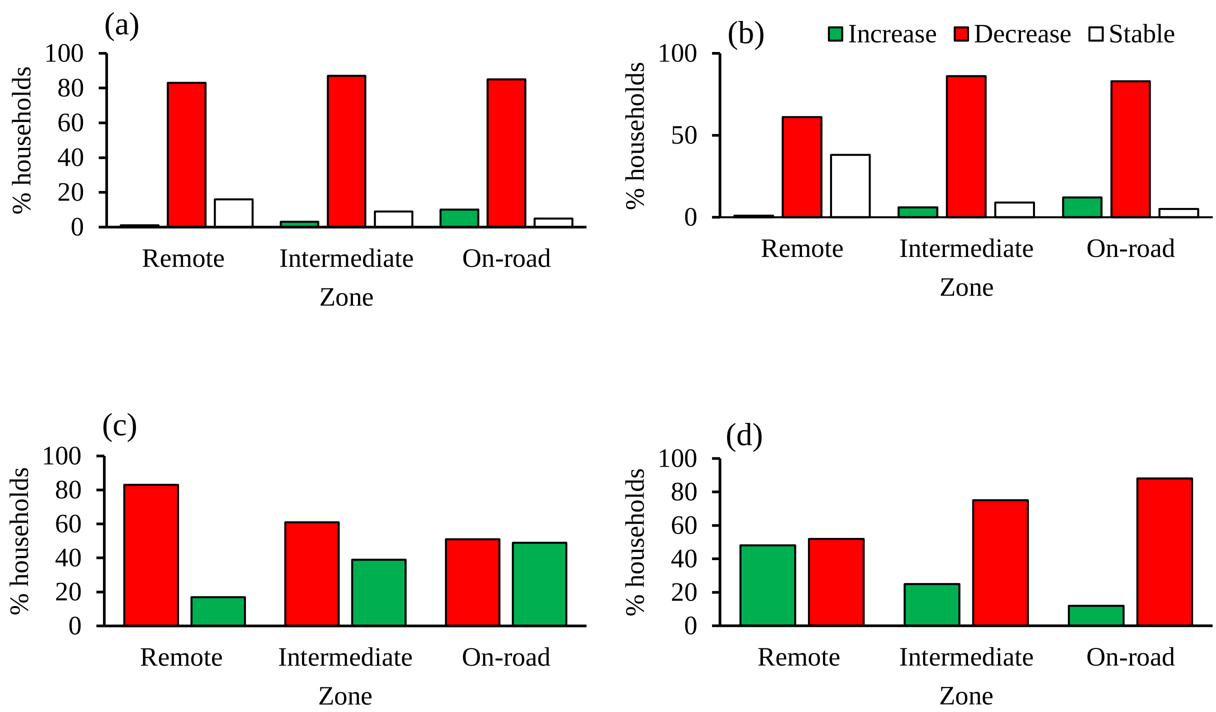

Figure 7: Perceptions of change in the most affected ecosystem services (a-construction materials, b-fuel wood, c- fresh water and d-wild foods) important for livelihoods

The changes in fresh water and wild food services reported by the households was different at the zone level. An overall difference of fresh water: X^2=22.32; $p<0.05$ and wild food: X^2=32.48; $p<0.05$ changes across the three zones was observed in chi-square test. A relatively high proportion of the households (83%) reported a decrease of fresh water in the remote zone compared to intermediate (61%) and on-road (51%) locations was found significant (X^2=20.25; $p<0.05$) in post-hoc test. Nearly half of the surveyed households in the villages of the on-road zone observed increased access to fresh water compared to 39% of households in the intermediate and 17% of the remote locations. The post-hoc test also showed a significant association of the fresh water service at the on-road zone (X^2=12.25; $p<0.05$). On the other hand, households in the on-road (88%) zone overwhelmingly experienced a decline of wild foods gathered from forest ecosystems, while fewer households in intermediate (75%) and remote (52%) areas experienced declines. In fact, half of the households surveyed in the remote location reported that access to wild foods has remained unchanged. Further analysis of post-hoc test also showed a significant association for wild food service for both the remote (X^2=28.09; $p<0.05$) and on-road zones (X^2=19.36; $p<0.05$).

4. Discussion

4.1. Trends of forest cover changes

Estimates of forest cover change (loss and gain) derived from Landsat images and drivers of deforestation identified by PRA participants exhibited diverse patterns both over the thirty years time period and within the different spatial contexts of the 3 zones. Overall forest loss and gain were higher in the on-road zone compared to intermediate and remote zones respectively. Though forest and tree cover increased from 1989-2003, households across all zones perceived continued loss over this time period. Local people perceived that the net loss of forest was higher than a small gain in plantations. Other studies across larger spatial extents have showed different trends in forest loss and gain. For example, the national assessment led by FAO (2015b) showed that the net growth of tree cover has remained stable since 1990, while a study undertaken by Reddy et al. (2016) reported a decline in forest areas in CHT region over 1930-2014. Different spatial and temporal extents may, in part, explain these discrepancies. Furthermore, while our results show a net gain in forest cover over time, details on the visibility and psychological impact (Alfonso et al., 2016) on forest loss vs. gain may also shape perspectives of forest dynamics (Twongyirwe et al., 2017). For example, loss can occur abruptly, as with forest harvest, whereas forest gain takes place at the rate of tree growth, which may be more difficult for individuals to perceive. Nonetheless, our localized zones highlight forest cover change is closely tied to local human activities and management.

Local community views on historical forest trends complemented the gaps in explaining detailed changes in the forest cover. To some extent, community experiences contradict the findings of the satellite imagery, but they also provide a detailed explanation of drivers for forest cover change. The findings were partly consistent with other study in Indonesia that remotely sensed forest cover change concurred with local perspectives in interpreting the declines of forest area (Fisher, 2012). In our study, to a large extent, perceived forest loss and gain does not corroborate the remote-sensing based findings. Rural people perceived more forest loss which was different to the observed dynamics (i.e. loss and gain) in satellite imagery analysis. Contrasting community perspectives with remote sensing data in locations with distinct vegetation and cultures, such as this study undertaken in the CHT region, provide perspectives on the complexities and limitations of relying entirely on satellite images or community responses to understand changes in forest cover. The small loss of forest areas after 2003 in remote locations identified by Landsat analysis was contrary to the community's experience of a severe decline. In particular, local communities viewed the natural forests have largely declined since the 1980s despite the increase of planted tree cover in government forest areas and private lands by little extent. The gain in forest cover is not a forest type that is particularly useful to the people for maintaining their important ecosystem services. As results the remote-sensing based estimates of a small forest gain may not infer well-being or livelihood outcomes. Though specific classification of monoculture plantation and natural forests was not taken into the analysis, community views made it clear that such forest gain were small and less likely to be improving the ecosystem services at the landscape.

Here there is evidence that variations in forest cover changes may be associated with the types of management regimes. Community-based management or secure tenure can result in positive social interactions, better forest conditions, and opportunities to increase tree cover and distribute economic benefits (Robinson et al., 2014). In the CHT region, we found perceived ecosystem service and forest loss were higher in the context of insecure tenure in remote villages managed under state command control approach. Despite people having open access to state forests in the remote zone, without devolved management and tenure rights, there are increasing threats from either agriculture expansion or illegal logging in the remaining natural forests. Limited ownership rights on farming lands thwart the community willingness to retain trees on their lands or fallow management for secondary forests. As a result there is less likely to gain of forest or tree cover in smallholders and reduce pressures on natural forests in the remote zone. Relatively better access and ownership of forests or trees held by smallholders in intermediate and on-road zones was associated with a small forest gain.

4.2. Drivers of forest cover changes differ over time and space

Changes in forest cover have demonstrated the influence of drivers to the loss and gain shifted between 1989 and 2014. Dynamic drivers contributing to forest loss in different social and ecological contexts have been reported by several studies (Geist and Lambin, 2002, Rudel et al., 2009, Hosonuma et al., 2012), in particular on variation of underlying causes over time and place (Sulieman, 2018). Harvesting of fuel wood and timber are common drivers, and here, play key roles in the loss of forests over time in the three locations of the CHT region. In particular since 2000, logging activities, mainly extraction of timber, increased in the intermediate and on-road zones and caused the loss of tree cover. Sloan and Sayer (2015) reported an increased demand of industrial timber and fuel wood in poor countries of the tropics since 1990, and will likely to accelerate forest loss in the Asia-Pacific region.

Any generalisation about specific drivers such as swidden farming as the main driver of deforestation may not be valid under changing forest cover. It is clear that swidden farming has been less influential for forest loss as only local community recognises it as threat in specific location. This finding contrasts previous studies that reported agriculture expansion by swidden farming practice is a common driver of forest loss for CHT region (Rahman et al., 2011, Kibria et al., 2015). These studies underscore the recent trend of forest cover and looming deforestation factors. In CHT region, more importantly forest management, land tenure and land quality determine the amount of swidden farming within a given context. However our finding agrees with a recent global study that asserted swidden farming may decrease in coming decades (Heinimann et al., 2017) while increase of commercial agriculture may lead to further deforestation (Shriar, 2014).

While swidden farming can be said as one potential explanation for forest loss, a number of other drivers likely play a role in forest change in the CHT. We found an expansion of monoculture trees and commercial agriculture with tobacco increased more exploitation of the forest resources in particular areas of intermediate and on-road. In the last decade, roads and market development played an important role in facilitating the timber trade from local smallholder teak planters.

Along with logging in private woodlots, illegal harvesting of timber further reduced natural tree cover to some extent. Fuel wood demand for small tobacco farms likely increased from 2000 to date further contributing to the forest resource extraction. Since 1985 tobacco cultivation started in the region with the cash crop reaching its peak during 2000-2010 contributing to increase extraction of fuel wood. The cultivation of tobacco continues in the intermediate and on-road zones.

Increases in tree cover in the CHT region has been driven by state led plantation programs aligned with the National Forest Policy of 1994, with a strong emphasis given on plantations through the resettlement of indigenous communities (Nath and Inoue, 2008). In the contexts of swidden farming, and in common with other upland regions, the dominant pathways to increasing forest cover is land allocation to local communities under state-control for tree development in the initial stage followed by market promotion (Bin and Alounsavath, 2016). In intermediate and on-road zones, state control, or reduction of the swidden farming, triggered expansion of tree cover was also reported in other studies (Kamwi et al., 2015). Reforested tree patches dominated by monoculture trees of timber or fruit crops replacing lands used in swidden farming has actually increased given secure tenure contexts and better access to markets (Ahammad and Stacey, 2016). Without secure tenure rights, people are less likely to invest their time and labour in retaining trees over the long term. Previous studies also showed that secure rights encourage people to plant trees and act in way to protect their tenure claims (Walters, 2012).

4.3. Impacts of forest cover changes on ecosystem services

Our work highlights community perceptions of changes in important ecosystem services affected by forest cover change in different landscape contexts. Over 80% of respondents reported reduced availability of ecosystem services (i.e. fuel wood, wild food and construction materials) required to meet their essential needs. Declining trends of fuel wood and wild food gathered from forest ecosystems pose the greatest threat to their livelihoods due to increased time spent collecting fuels and foods, as well as due to health risks associated with the loss of nutrient-rich forest foods. These results are similar to the findings of Ehara et al. (2016), which also report that due to declines of forest areas, the number of households using the ecosystems services from forests have decreased and travel times to gather forest products have increased.

Loss of forest cover is often accompanied by declines in ecosystem services, but patterns of forest loss and effects on ecosystem services and livelihoods varied by zone. A relatively high decline of fuel wood was associated with intermediate and on-road zone, which were more distant from forests. Though the people in the remote area were affected by high forest loss, they also have better access to fuel wood due to close access to natural forests. On the other hand, participants perceived increased shortage of fresh water in the remote zone near the forest, while participants perceived improved access to freshwater in the intermediate and on-road zones. Adequate access to water also means that the considerable amount of time women and children spend fetching water can be spent on more productive tasks that improve livelihoods and economic productivity, a key component of poverty alleviation (van Jaarsveld et al., 2005). Though people in all the zones have been affected with the shortage of timber construction materials, this shortage is increasing in thon-road zone.

The changes in forest cover was highly concerning to the local communities in the CHT, particularly the loss of natural forest have negatively affected their well-being over time. The decline of fresh water sources was largely evident in the remote areas where the highest level of natural forest loss was reported, while access to fresh water increased in the intermediate and on-road zones despite the loss of natural forest. This paradox implies no association of natural forest loss and water shortage. Indeed, fresh water supply increased due to installation of gravitational force system for withdrawing water from springs in the intermediate, and underground in the on-road zones. Nevertheless technical solutions only improve water provisions to some extent before the capacity of natural capital is reached (Alfonso et al., 2016). Furthermore, higher food shortage also persists within the remote villages (Ahammad and Stacey, 2016). These persistent food shortages suggest the decline of natural forests, which are sources of wild foods will exacerbate the food shortages of the adjacent communities.

5. Conclusions and policy implications

By combining satellite data and community experiences, our study examined the patterns of forest cover changes and the variations in drivers and impacts on ecosystem services in the eastern upland Chittagong Hill Tracts region of Bangladesh, between 1989 and 2014. In doing so, it is evident that different methods of assessment provide contrasting results, but integrating local experiences can minimise the knowledge gaps between satellite information and local perceptions in understanding forest changes. The integrated methods can be effective in particular in a data poor region within Bangladesh and elsewhere where limited historical information on forest management exists. Integrating remote sensing application with field surveys can address social and cultural perspectives of forest management which could not be possible with other independent methods. In addition our study showed that the drivers of forest cover changes were dynamic and affected different populations differencing across a diverse landscape. Without accounting for the dynamics of drivers over time, forest management may fail to avoid potential sources of deforestation in the landscape.

The analysis of ecosystem services based on people's perceptions reveal some potential aspects to be addressed in management and decision making of forest resources in the CHT region. It raises concerns about the ineffectiveness of the present management strategies in maintaining ecosystem services. Although there is no alternative to plantation in the landscape of the CHT, the challenges remaining in existing forest management are to improve synergies within entire range of ecosystem services. Due to associated trade offs of plantations observed in the region, a systematic assessment would be useful to understand the relationship between forest types and multiple ecosystem services, their management and stakeholders involved at local and regional scales. At present there is scarce information or assessment on entire ecosystem services in the landscapes while the current study only explains the key contributing forest ecosystem services affected based on perceptions. A quantitative assessment of ecosystem services under alternative forest management scenario and the roles of stakeholders would be useful in supporting decision making for integrated land management. In this regard, both economic and non-economic approaches including mapping of ecosystem services including cultural perspectives in the assessment of ecosystem services may be required.

Finally, the present study may shed lights on some key management issues to improve forest conditions and sustainable provisions of ecosystem services in the region. One of the key limitations in the current forest management is the lack effective integration between land managements and understanding their associated trade-offs in ecosystem services. In this regard, inter-regional difference in terms of specific land tenure and biophysical conditions for agriculture food production will be an important consideration in success of forest and tree management. It is because the state approach to restrict swidden farming and allowing plantations may not have positive outcomes for local livelihoods and long-term provisions of ecosystem services. Furthermore, considering the difference in the demands of forest ecosystem services across social and ecological contexts of the region, an adaptive management strategy requires benefit local communities in terms of access to the forest, land ownership and alternative economic opportunities. A programme should be designed for integrated land management of trees with fruit crops to ensure diverse needs in local livelihoods, sustainability of the agriculture production and maximise provision of forest ecosystem services.

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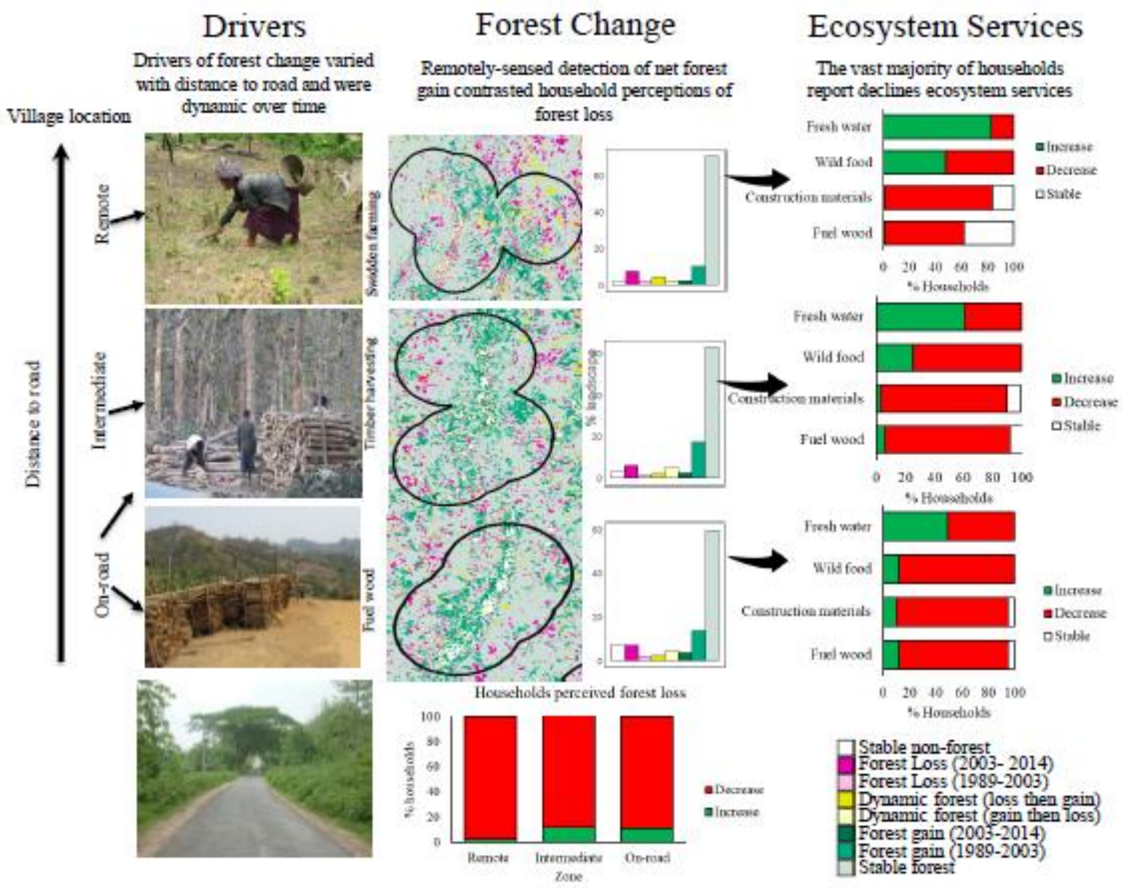

Graphical abstract