Assessing Asian Elephant Habitat in South-Eastern Bangladesh

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Abstract. Small numbers of Asian elephants remain in pockets of forest within south-eastern Bangladesh. An analysis of Landsat images indicated ≈ 36% of elephant habitat loss from 1989–2015, and a 2015 ground inventory of 7 habitat patches, revealed decreasing canopy cover. Vegetation communities were dominated by non-native species, and dung surveys suggested elephants were favouring habitat patches with relatively more tree and bamboo species, and canopy cover. Given recent geo-political developments in Bangladesh, effective elephant conservation requires urgent habitat restoration that also addresses human requirements.

Introduction

Wildlife habitat continues to disappear at an alarming rate across the globe (FAO 2016). This is particularly evident in the case of large mammals that require extensive home ranges to meet life history requirements (Leimgruber *et al*. 2003). The fundamental driver of habitat alteration has been human population growth, resulting in a large proportion of the earth's natural habitats being converted into agricultural land, human settlements, roads, industrial areas and other anthropocentric uses. Further, as continuous habitat becomes fragmented, degraded and reduced in quality, wildlife may come to persist only in less suitable remnants or 'habitat islands' – leading to other factors taking a toll, such as edge effects and deleterious inbreeding. In Southeast Asia alone, 79 mammalian, 49 avian and 184 amphibian species are now threatened due to rapid loss of habitat, primarily deforestation (Li *et al*. 2016). The retention and restoration of natural habitat is thus a critical tool in stemming the loss of species. A critical first step is quantifying and assessing the status of remaining habitat, thus providing a foundation to devise realistic habitat restoration plans.

The natural habitat of the Asian elephant (*Elephas maximus*) is undergoing increasing reduction and fragmentation across all 13 Asian countries where it occurs. Nearly 20 years ago, Leimgruber *et al*. (2003) estimated that approximately half of the land inhabited by Asian elephants had become fragmented and unable to support large populations, and Sukumar (2003) calculated that the species was restricted to only 15% of its historical range. These figures likely are now very conservative, given approximately 20% of the earth's human population is also living in or near the current range of the Asian elephant (Stevenson & Walter 2006), leading to continuous habitat encroachment and conversion (Rood *et al*. 2010). Indeed, during 2000–2016, approximately 480,000 ha of natural forest was removed each year in southeast Asia (Li *et al*. 2016). A consequence of these trends likely is an increase in the frequency of encounters and conflicts between humans and elephants.

Nowhere is the loss of Asian elephant habitat more pronounced than in Bangladesh, where a rapidly growing (density 964 /km^2; BBS 2010) and predominantly poor human population has severely impacted the indigenous population of elephants (210–330 individuals remaining; Motaleb *et al*. 2016). Further, the forest cover of the country declined from nearly 20% to 9% during 1963–2003 (Brown & Durst 2003). The influx of Rohingya refugees from Myanmar and their encroachment on elephant habitat has ex-

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acerbated this situation (Rahman 2019). Consequently, any remaining elephant habitat has likely decreased significantly in quality, in terms of providing forage, cover, and other resources required to support healthy elephant populations. Traditional migration routes also may have become disrupted as the animals become dependent on small patches of forest.

Despite the obvious plight of the Bangladeshi elephant population, qualitative information on the status of remaining elephant habitat (e.g. vegetation cover and land-use) is scant. Moreover, a formal assessment of remaining elephant habitat is essential to begin stabilising (much less reducing) detrimental impacts on elephants, minimising human-elephant conflicts, and devising a comprehensive habitat restoration plan. Herein we present the first formal assessment of elephant habitat in the southeast region of the country, in order to (i) ascertain changes in elephant habitat during 1989–2015 and (ii) understand the current status of elephant habitat in terms of providing forage and cover.

Methods

Site description

The study was conducted in the Chittagong and Cox's Bazar districts (administrative units) of south-eastern Bangladesh. This region consists of hillocks, hills, valleys and forests ranging from 30–300 m elevation. The temperature ranges between 26–33ºC, and annual precipitation from 280–370 cm per year (Bangladesh Meteorological Department 2017). The forests in this area are tropical semi-evergreen, with moderate floristic and faunal diversity (Biswas & Choudhury 2007). The current annual deforestation rate in the country is less than 1%, with per capita forest land at approximately 0.022 ha (FAO 2016). Extensive agricultural areas and human settlements exist inside and surrounds remaining forest. Regional data are not available but the population growth rate for the country is 1.43%. Despite legal restrictions on entering forests, compliance is weak due to a lack of enforcement capacity. Almost all natural forests have been altered or converted into secondary forest or plantations with mostly non-native species, either intentionally or due to human disturbance.

Satellite image classification

Landsat imagery with 30 m resolution was acquired and used to identify forest loss that occurred within the study area during 1989–2015. Within each time period we selected imagery with minimum atmospheric haze, particularly those outside the monsoon season. Four sets of satellite imagery were selected: February 22, 1989 (acquired by Landsat 5 TM); November 7, 2001 (acquired by Landsat 7 ETM); January 23, 2010 (acquired by Landsat 5 TM) and November 21, 2015 (acquired by Landsat 8 OLI) (Source: USGS Explorer).

The different spectral bands (i.e. red, green, blue, near infrared and short-wave infrared 1 and 2) of the imageries were stacked. The images were first projected to UTM zone 47N to match the geographical projection of the reference data. The study area was delineated using the existing forest divisional maps prepared by the divisional offices of the Bangladesh Forest Department. On-screen digitalisation of the study area boundary was produced using both hard-copy maps and Google EarthTM. The boundary polygon was converted to a shape file format using ArcGIS Desktop 10.3.1 software.

ERDAS Imagine software (HEXAGON Geospatial, Version: 15.1) was used to carry out supervised classification based on six land cover classes, namely forest, degraded forest, agriculture, settlement, hill shade (where satellite ground cover was not achieved) and water bodies. At least ten training samples were defined for each land cover class. The land cover classifications assigned by the classifier were post processed using the clump-and-eliminate procedure to remove mixed classes and take care of salt-and-pepper error (Reddy *et al*. 2016). The thematic maps were then converted to shape files and imported into ArcGIS Desktop software to process layout and area calculation. Throughout the operation, historical satellite photos from Google EarthTM were used to corroborate logical class boundaries and the spatial distribution of classes.

Ground inventory of elephant habitat

In May – August 2015 we surveyed and sampled habitat patches of the study area where elephants reside (Fig. 1). Security issues constrained the area that could be worked. For sampling, we selected two districts of the area (Chittagong and Cox's Bazaar) where most of the resident elephants in Bangladesh were found (Motaleb *et al*. 2016). Within these districts, 15 candidate habitat patches were identified and from these, seven were selected randomly for ground sampling (Fig. 1, Table 1). The patches were largely encircled by villages and other development.

Within each of the patches, we established plots using a grid interval of 2.76 km x 1.86 km (1°30′ x 1°00′). Each plot coordinate was calculated prior to the start of fieldwork. A GPS instrument (Garmin 78) was used to locate each plot centre. The numbers of plots sampled in each habitat patch are summarised in Table 1. Additional details appear in Chowdhury (2018).

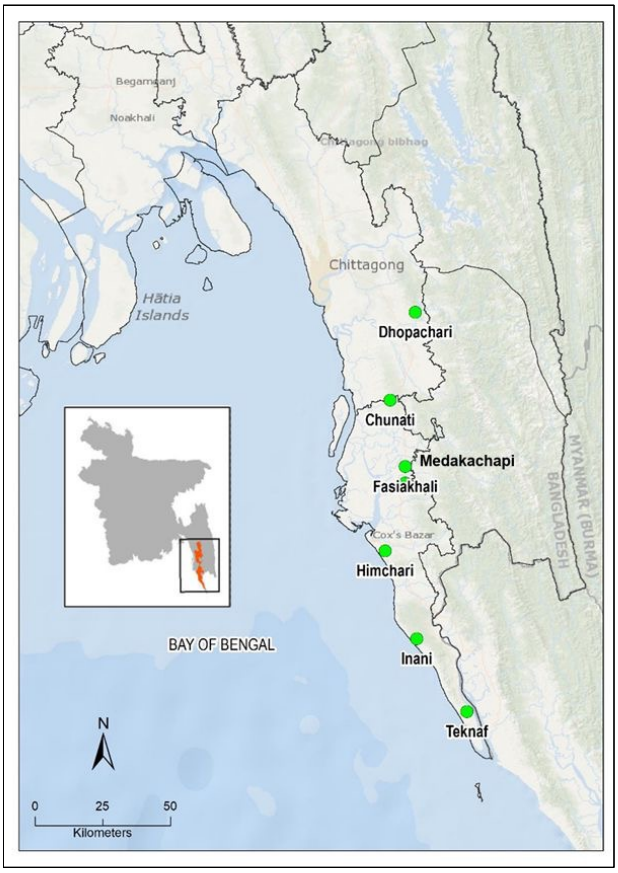

Figure 1. Map showing location of study's habitat patches in south-eastern Bangladesh.

Table 1. Number of sample plots surveyed in habitat patches arranged by patch size.

Patch	Latitude & Longitude	Area (km^2)	No. plots
Medakachhapia	21°41′16″N, 92°09′22″E	4.0	4
Fasiakhali	21°40′00″N, 92°08′00″E	13.0	6
Himchari	21°21′17″N, 92°02′50″E	17.3	5
Inani	21°08′24″N, 92°04′56″E	29.3	7
Dhopachari	22°13′36″N, 92°06′79″E	47.2	11
Chunati	21°54′00″N, 92°08′00″E	77.6	14
Teknaf	21°04′00″N, 92°09′00″E	116.2	10

Using the plot centre, we sampled habitat using three nested circular plots. Within the large plot (17.84 m radius, or 1000 m^2), we measured the height and diameter breast-height (DBH) of all trees >10 cm DBH and identified bamboo to species and counted stems (none exceeded 10 cm DBH). The tree and bamboo counts were combined into a single metric (average number trees+bamboo) as we felt this provided a single composite measurement of habitat quality for elephants. Also, at each plot centre we measured canopy cover using a densiometer.

Within mid-sized plots (10 m radius), DBH and height of trees 5–10 cm were measured and recorded. Inside small plots (2 m radius), we counted all live seedlings and saplings and visually estimated tall grass coverage (%).

Forest regeneration index

We used a forest regeneration index (FRI) that reflects the regeneration capacity of the habitat patches and, overall, the health of the patch ecosystem (Shirer & Zimmerman 2010).

We calculated FRI for each of the small plots as:

FRI = (20 x SEEDLING COUNT) + (50 x SAPLING COUNT)

FRI values were assigned into four categories based on their magnitude (Table 2).

Table 2. Forest regeneration categories adapted from Shirer & Zimmerman (2010).

Categories	Index Range	Stem density per ha	
		Seedlings	Saplings
Poor	0–200	<1899	<758
Fair	201–400	1900–3799	759–1519
Good	401–600	3800–5700	1520–2280
Very good	>600	>5700	>2280

Forage species categorisation

We compiled a list of forage plants eaten by elephants as reported by Joshi & Singh (2008) and Feeroz (2014). For each forage species, percent cover in the large plots was visually estimated. We used this as an indication of abundance within the study area. Species were categorised in each plot as 1 = very common (>60% of plot), 2 = common (40–60% of plot), 3 = fairly common (20–40% of plot) or 4 = infrequent (<20% of plot). The average for all plots in each habitat patch was taken to represent that patch.

Phytosociological attributes

We calculated the Importance Value Index (IVI) for all tree and bamboo species recorded across the large and mid-sized plots in each habitat patch (Curtice 1959; Joshi *et al*. 2019). Species diversity for each patch was calculated using the Shannon-Weaver (1963) index of diversity (Pielou 1975).

Dung counts

Within each large habitat plot we conducted dung pile counts as an indirect assessment of habitat use by elephants (Barnes 2008). Following Kumar *et al*. (2010) and Rood *et al*. (2010), we searched for and counted all dung piles other than those that were severely eroded, weathered and/or deformed to provide a crude assessment of elephant activity in the patches. Ahrestani *et al*. (2018) discusses the limitations of using dung counts to estimate densities. In this study logistical and safety considerations prevented more precise estimates through tracking dung pile decay rates and changes in appearance. The average number of dung piles per plot was calculated for each patch and used to represent elephant use.

Data analysis

All habitat data were entered into Microsoft Excel and analysed using statistical software Minitab 17 (Version: 17, Minitab Inc). We used simple linear regression to assess the relationship between elephant usage (dung piles) with the mean number of tree and bamboo species present, canopy cover and patch size.

Results

Land use/land cover (LULC) change

Figure 2 shows spatial changes of LULC, with corresponding class area statistics in Table 3. Our analysis indicated that ≈ 36% of forest area was converted to other land uses during 1989–2015 with approximately 21,183 ha of forest removed from 2010–2015 (Table 3). Over that time period, this equates to an annual deforestation rate of ≈ 1.7%.

Vegetation structure

The distribution of FRI categories varied by habitat patches (Fig. 3). Only two habitat patches (Dhopachari and Medakachapia) had the majority of plots falling in the Very Good or Good categories (73% and 100%, respectively). Average canopy cover for the 7 patches was ≈ 31% (SD = 17.81; Table 4). The highest percentage of tree species occurred in the lower DBH size classes and gradually decline up to the larger size classes (Fig. 4). The highest average tall grass cover measurements occurred in the Teknaf patch, followed by Himchari, Innani, Dhopachari, Chunati, Medakachapia, and Fasiakhali, yet these values ranged from only 2–17% (Table 4). Dhopachari and Chunati had the highest estimated clump and culm densities for bamboo, compared to the other patches (Table 4). We detected 40 different species of elephant

Table 3. Land Use/Land Cover (LULC) changes in south-eastern Bangladesh.

LULC class	Area (ha)				% Change
	1989	2001	2010	2015	1989–2015
Agriculture	59,492	69,999	69,019	96,249	+ 62
Settlement	17,565	32,075	36,335	42,011	+ 139
Forest	60,542	52,604	50,234	29,050	- 52
Degraded	76,363	74,954	67,361	58,634	- 23
Water body	18,705	4,343	10,103	7,284	NA
Hill shades	2,056	749	1,670	1,495	NA

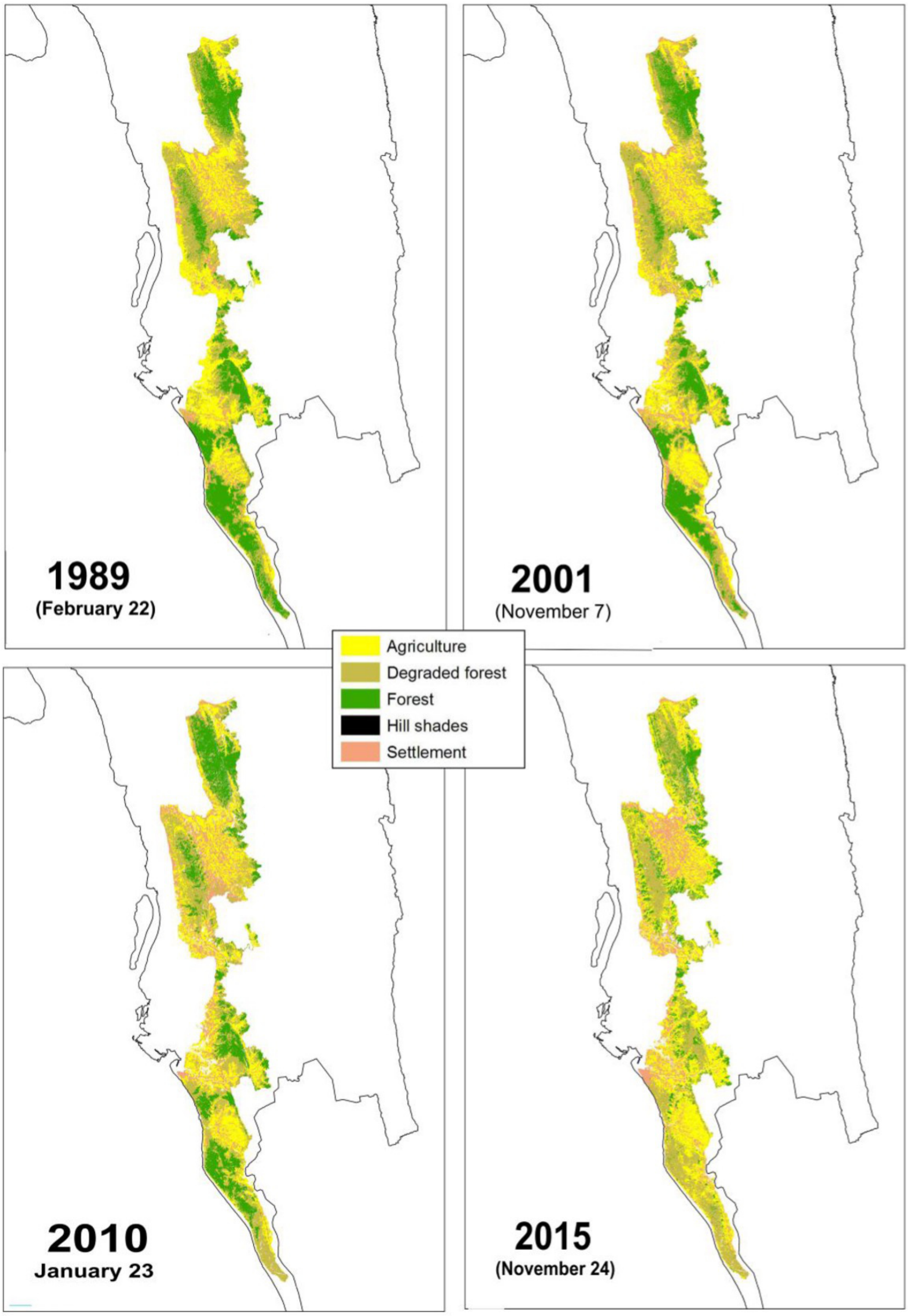

Figure 2. Satellite imagery showing land use changes in south-eastern Bangladesh.

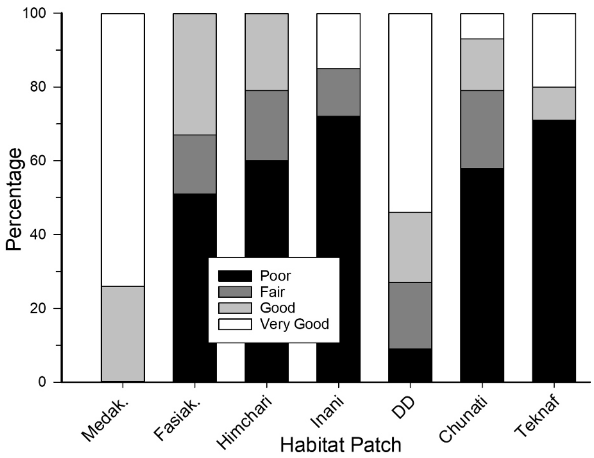

Figure 3. Forest regeneration index (poor, fair, good, very good) composition of 7 different habitat patches arranged from smallest to largest in area.

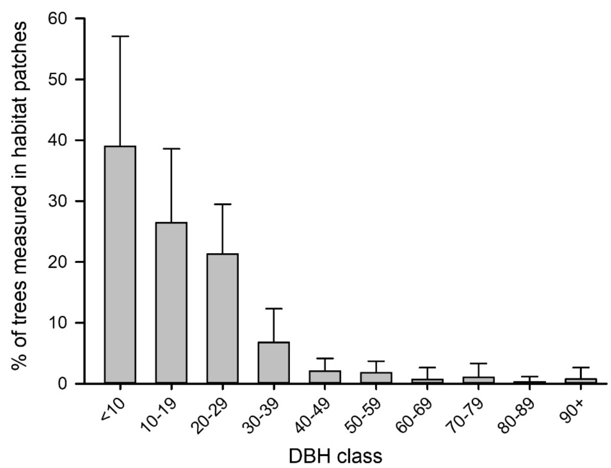

Figure 4. Distribution of tree diameters (DBH) in habitat patches (all patches pooled). Error bars = ± 1 standard deviation.

food plants across the seven habitat patches (see Appendix C in Chowdhury 2017). Their relative abundance ranged from rare to quite common. The Shannon-Wiener Index of patches ranged from 2.10–3.33 except for Himchari and Fasiakhali. Himchari displayed the greatest evenness followed by Fasiakhali (Table 4).

Phytosociological attributes

In 3 of the 7 habitat patches a non-native species occurred within the top three IVI values of detected plant species (Table 5). One non-native species, *Acacia auricularis*, held the highest IVI value in 3 sites (Inani, Teknaf and Chunati). One of the signature taxa for the study region (*Dipterocarpus* spp.) showed a dominant IVI value only in the Medakachhapia and Fasiakhali habitat patches; another historic key taxa, *Syzygium* spp. had the highest IVI value in Himchari and second highest in Fasiakhali, but failed to place in the top three IVI species in the other patches.

Elephant habitat use

We detected elephant dung piles in all seven habitat patches, and 61% (35/57) of all plots. A strong positive relationship existed between the average dung pile count and the average number of tree plus bamboo species in each patch ($F = 39.6$, $df = 1, 5$, $P < 0.001$, $R^2 = 0.86$, see Fig. 5). A similar strong relationship was found with canopy cover ($F = 8.1$ $df = 1,5$, $P < 0.04$, $R^2 = 0.62$). Dung pile counts were not related to the number of forage species ($F = 2.3$, $df = 1,5$, $P = 0.19$, $R^2 = 0.32$) nor patch size ($F = 0.01$, $df = 1,5$, $P = 0.91$, $R^2 = 0.03$).

Table 4. Vegetation measurements for 7 different habitat patches in south-eastern Bangladesh. Clump and Culm represent estimated bamboo density, SW = Shannon-Wiener diversity index, CC = canopy cover, and TG = tall grass cover.

Patch	Clumps/ha	Culms/ha	SW	Evenness	% CC	% TG
Teknaf	11	138	3.11	0.80	31	17.0
Inani	14	97	3.10	0.84	26	9.3
Himchari	4	44	1.04	0.95	9	12.4
Medakchhapia	12	240	2.10	0.74	55	4.2
Fasiakhali	7	22	1.89	0.71	40	2.3
Chunati	31	175	2.51	0.87	21	6.6
Dhopachari	162	1449	3.33	0.88	43	8.2

Table 5. Plant species (all elephant forage species) demonstrating the three highest Important Value Index (IVI) values within each of 7 surveyed patches of elephant habitat. The NN superscript indicates non-native species.

Patch	Species	IVI
Medakachhapia	*Dipterocarpus* spp.	131.9
	Mangifera indica	34.1
	Artocarpus heterophyllus	19.3
Fasiakhali	*Dipterocarpus* spp.	89.7
	Syzygium frimum	60.6
	Mangifera indica	40.1
Himchari	*Syzygium* spp.	140.0
	Albizia sp.	98.4
	Spondias mombin	61.6
Inani	*Acacia auriculiformis* NN	44.9
	Ficus bebghalensis	41.1
	Dipterocarpus spp.	14.2
Dhopachari	*Ficus hispida*	36.1
	Stereospermum coais	31.0
	Grewia nervosa	19.5
Chunati	*Acacia auriculiformis* NN	35.6
	Ficus hispida	34.5
	Callicarpa arborea	28.3
Teknaf	*Acacia auriculiformis* NN	73.1
	Erythrina fusca	29.5
	Gmelina arborea	19.5

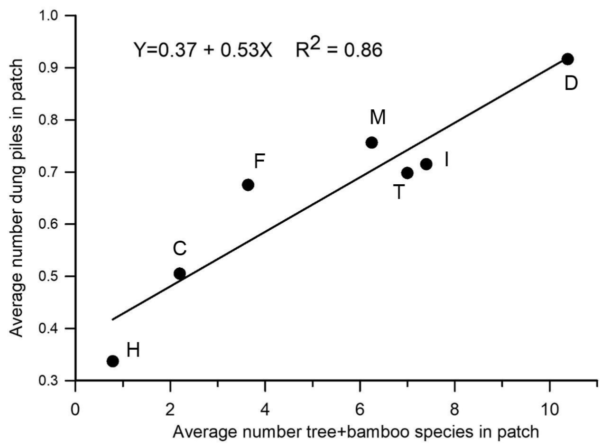

Figure 5. Relationship between average number of dung piles and average number of individual trees+bamboos across plots established within in each of 7 patches of habitat (number of plots vary depending on size of patch). Letters represent initials for the names of the patches (see Table 5 for full names).

Discussion

The overall annual deforestation rate we estimated for the study period (1989–2015) was higher than the national rate of 0.77% reported for 2006–2014 by Reddy *et al*. (2016). Nationally, this represented » 31% (36,275 ha) of elephant habitat being lost due to land conversion (unpublished data, Bangladesh Forest Department), similar to the 36% we detected in our region. The habitat loss in our study area is likely to continue. The LULC change also shows that forest and degraded forest are being fragmented, making the habitat discontinuous.

The consequences of LULC changes are multifold. Habitat loss may require elephants to seek forage, cover and other resources in new areas. As they extend their search, conflict with humans will rise (Chowdhury 2017). Blake *et al*. (2008) found the movement rate of African elephants (*Loxodonta africana*) in the Congo Basin increased 14-fold when they were crossing human-dominated landscapes, presumably to minimize risk of exposure. Our findings suggest that elephants in south-eastern Bangladesh may be forced to forage larger distances and to expend more energy. Elephant populations are unlikely to be sustainable over the long term, under such conditions.

Open patches in forest ecosystems often serve to increase biodiversity (Muscolo *et al*. 2014), but an unnaturally high predominance of young vegetation may suggest impediments to natural succession and forest maturation. The FRI values we observed, indicate poor forest regeneration in most habitat patches. Likely a number of factors suppress tree maturation in the region. Scarcity of firewood leads villagers to set fire to the existing vegetation in order to collect the resultant dead wood. Anthropogenic exploitation of these forests may hold patches in an early seral state, reducing shade for elephants. A preponderance of small diameter trees in the habitat plots indicates reduced maturation rates and potential long-term changes in species composition of the plant community. This may impact habitat quality for the elephants. However, lower basal area or fewer trees/ha also may produce more forage at ground level (Moore & Deiter 1992). The absolute loss of forest habitat may be more visible, but more subtle alterations of stand structure may also contribute to a decline of suitable elephant habitat.

The abundance of tall grasses and bamboo was low in our study patches. Elephant diets can contain 3–14% of grasses (Sukumar 1992; Joshi & Singh 2008). Tall forage grasses like sungrass (*Cypetus difformis*), and ful jharu (*Thysanolaena maxima*) are collected for roofing and makeshift brooms. Bamboo when present constitutes an important forage species for elephants. We detected a wide range of abundance of bamboo across the habitat patches, which likely reflects differences in local harvesting pressure. Excessive harvesting of bamboo and tall grasses by humans would add to the pressure on elephants to look for alternative food sources. Synchronous bamboo flowering which occurs once in 30–40 years, with all mature plants dying after fruiting, may partially explain the low levels of bamboo observed, as villagers stated that such an event occurred 3–4 years before.

Plant community domination by non-native species (*Acacia auriculiformis*, *Eucalyptus camaldulensis*) may have a profound impact on regeneration, growth and abundance of elephant forage species. The prevalence of non-native species may alter elephant habitat use (Prasad & Williams 2011). The historical multi-storied forests of Bangladesh are now converted to single-storied forests with minimal or zero ground cover (Hossain 2003). Non-native species like Eucalyptus and Acacia inhibit natural regeneration of some native forest species and influence the distribution, quantity and seasonality of natural forage, making habitats less favourable (Islam *et al*. 2003; Carnus *et al*. 2006). The domination of non-native species is not unexpected in an environment where exotic plants have been deliberately introduced since 1871, a notable example being teak (*Tectona grandis*). Other species (e.g. *Acacia auriculiformis*, *Eucalyptus camaldulensis*) were introduced in the 1980s for large scale afforestation, with the objective of replacing low yield heterogeneous forests with commercially-valuable species (Hossain 2003). The fact that most native species showed lower IVI values indicate their scarcity and need of high conservation priority. The domination of non-native species may result in the extinction of more palatable species (Hossain 2003), although the diversity of the habitat patches appeared relatively similar to that reported for other tropical forests.

The use of animal sign such as dung piles is a strong indicator of animal presence but is less reliable for assessing abundance or frequency of use (Williams *et al*. 2002). The positive relationships between dung counts and the tree/ bamboo community observed by us suggests that this method provides a valuable assessment tool. Our results suggest that the animals had recently occupied the habitat patches, so presumably the patches provided some level of resources (including thermal refuge). Elephant use of high- canopy cover forest may be less, as medium and open canopy cover provide more forage (Sitompul *et al*. 2013). However, our results suggest that elephants respond positively to habitat patches with high canopy cover and a more diverse community of trees.

This study highlights the alarming rate at which elephant habitat in south-eastern Bangladesh is diminishing and degrading. A comprehensive habitat restoration program is urgently required to save this iconic and important species from extirpation. Although this study focused on remnant habitat patches, connectivity must also be maintained and has to be addressed in any habitat restoration program. Habitat restoration is not straight forward in a human-dominated landscape like Bangladesh. This study was conducted before the influx of well over three-quarters of a million Rohingya refugees into Bangladesh (UNHCR 2020). A large proportion of them have taken shelter in environmentally sensitive areas such as national parks, reserve forests, or agriculturally marginal areas including Teknaf and Ukhiya Upazila of Cox's Bazar (Imtiaz 2018). The settlements have led to increased demands on natural resources. For example, Hasan *et al*. (2018) suggest that the refugees required 750,000 kg of firewood every single day. Consequently, there has been an increase in conflicts between humans and elephants (Rahman 2019). Thus, habitat restoration needed to retain Bangladesh's elephants must not only safeguard elephant habitat but also address the root causes of human-elephant conflict.

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