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Application of Multi-Species Occupancy Modeling to assess mammal diversity in northeast Bangladesh

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ABSTRACT

Bangladesh is one of the most densely populated countries on earth with 1033 persons/km^2, yet it also harbors a high level of mammal diversity. Unfortunately, general ecological knowledge is limited in many areas of the country, leading to a lack of cohesive conservation initiatives. As a result, the country is quickly losing integral wildlife habitat. Here we assess the presence and community composition of mammal species in Northeastern Bangladesh. Between May 2014 and January 2015 we conducted camera trapping in four Reserve Forests in Northeastern Bangladesh: Atora Hill Reserve Forest (Atora Hill), Patharia Hill Reserve Forest (Patharia Hill), Rajkandi Reserve Forest (Rajkandi), and Tarap Hill Reserve Forest (Tarap Hill); for a combined total of 1283 trap nights across the four reserves. We then used a Multi-Species Occupancy Model (MSOM) to estimate mammal species occupancy, richness, and community composition in Northeastern Bangladesh. We recorded 27 species of mammals, 23 of which were non-domesticated mammals, consisting of six orders and 15 taxonomic families. Our model suggests there are potentially 37 species of mammals occur in the Northeast Bangladesh. MSOM model also suggests occupancy for each species varies in the region from 69 percent for wild boar (*Sus scrofa*) to 0.1 percent for small Indian Civet (*Viverricula indica*). Our study provides the baseline for mammal species richness and community composition in Northeastern Bangladesh. Based on our findings we recommend that public-private partnerships, targeted protected areas, and increased capacity of the local people, are integral to facilitate coexistence between humans and wildlife and to aid in the conservation of mammal diversity in Northeastern Bangladesh.

1. Introduction

Areas of high biodiversity and dense human populations commonly co-occur in tropical developing countries, and protected areas in these human-dominated landscapes tend to be small and fragmented (Quazi and Ticktin 2016). Effective conservation strategies must address the role of these smaller protected areas and any surrounding forested landscapes, but a

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lack of scientific information presents an obstacle to conservation planning (Bernard et al. 2013, 2014; Muzaffar et al., 2011; Quazi and Ticktin 2016). This is especially true in Asia, where conservation practices often lack the scientific knowledge needed to inform official policy (Sunderland et al., 2013). Despite being fragmented, the forest patches in tropical Asia can harbor species of global concern, especially if they are in close proximity to larger, forested landscapes. For example, forest fragments in Borneo and Sumatra have been shown to have high species diversity (Bernard et al., 2014; Granados et al., 2016; Weiskopf et al., 2019).

Although Bangladesh is one of the most densely inhabited countries on earth with 1033 persons/km^2 (BBS 2011), it also harbors a high level of mammal diversity that is primarily confined to three different regions: the Sundarbans (the largest mangrove forest in the world), the Northeast (Habigonj and Moulovibazar district of the Sylhet Division), and the Southeast (Chittagong Hill Tracts (CHT), and the greater Chittagong area). Several threatened or endangered mammal species have been recorded from these regions, including: Asian elephants (*Elephus maximus*), gaur (*Bos gaurus*), dhole (*Cuon alpinus*), tigers (*Panthera tigris*), Indo-Chinese clouded leopards (*Neofelis nebulosa*), fishing cats (*Prionailurus viverrinus*), sambar deer (*Rusa unicolor*), and Western hoolock gibbon (*Hoolock hoolock*) (Khan 2004; Chakma 2015; IUCN Bangladesh 2015). However, recent economic growth, unplanned development, and increasing demand for agricultural land, combined with a general lack of ecological knowledge on existing wildlife distributions has hindered the formation of effective measures to conserve biodiversity in the country (Muzaffar et al., 2011).

The Northeastern region is a particularly important target for conservation initiatives, as it is contiguous with the Manas-Namdhapa tiger conservation landscape of India and anecdotal reports of high species diversity have been recorded (Sanderson et al., 2006). The region has also experienced recent rapid human development. Over the last two decades, since the reestablishment of democracy, much of the forest has been cut down to make way for roads and highways, tea, rubber, and betel leaf (*Piper betel*) plantations, natural gas mining, and for other agricultural uses (Islam et al. 2013; Quazi and Ticktin 2016). Quantifying the ecological value of remaining forested areas is an urgent step in developing conservation initiatives before complete deforestation occurs. One indicator of ecosystem health is the presence and diversity of mammalian species.

The use of camera trapping has grown exponentially over the last decade, doubling every 2.9 years (Burton et al., 2015). In biodiversity monitoring and ecological research, camera trapping has been used over a broad geographic range, taxonomic diversity, and to address diverse conservation issues (Steenweg et al., 2017). Camera trapping has been proven an effective tool for answering various ecological and conservation questions, including: species landscape connectivity, evaluating effects of forest fragmentation on tropical species diversity, assessing species richness and recording the loss of specific species (Ahumada et al., 2011; Barrueto et al., 2014; Rasphone et al., 2019).

Multispecies Occupancy Models (MSOM) are one way in which inferences of occupancy and detection probabilities, as well as associated parameter estimates, can be generated for all species in a sample (Kéry and Royle 2016). In MSOM, modeled parameters for each species can be informed by the species-specific capture history as well as from the community pool of capture histories, which is advantageous for modeling species with lower detection probabilities, as are often present in non-invasive surveys of mammals. A MSOM applies random effects to predict not only probability of occupancy estimates for each species, but also provides inference about species richness for the region.

Here we use MSOM and species accumulation curves to assess the presence, community composition, and species richness of mammal species in Northeastern Bangladesh (Kéry and Royle, 2016; Iknayan et al., 2014). This is the first effort to quantify mammal diversity and occupancy in the region and provides important insight into what actions are needed to conserve biodiversity in this region of Bangladesh.

2. Study area

Northeastern Bangladesh is contiguous with the Manas-Namdhapa tiger conservation landscape of India, and once harbored a diverse array of forest types, from tropical evergreen, to mixed and or semi-evergreen forest (Sanderson et al., 2006). The landscape is now heavily fragmented, and the remaining forest is mostly confined to ten patches varying in size from 10 to 100 km^2 (Bangladesh Forest Department 2012). There is one wildlife sanctuary (IUCN category IB), and two national parks (IUCN category II) among those forest patches. The other seven patches are classified as Reserve Forests as declared under Bangladesh's Forest Act of 1927. All ten forest patches are bound between N24.07, E91.25 and N24.36, E91.13 and managed by the Bangladesh Forest Department (BFD).

The topography of Northeastern Bangladesh is hilly with elevations ranging from 50 to 300 m ASL. Numerous streams and swampy areas crisscross the region. Remaining forests are mostly of three types: hill forest, shrubs, or mixed bamboo forest (Forest Department of Bangladesh 2012). Annual temperature ranges from 32 °C (August–October) to 9 °C (January), and nearly 80% of the annual average rainfall (3334 mm) occurs between May and October (Quazi and Ticktin 2016).

From the ten forest patches, we chose four to survey based on their size and accessibility, (i.e., could we reasonably and safely access the forest). The chosen forest patches varied in total area. Atora Hill Reserve Forest (Atora Hill) is ~100 km^2, Patharia Hill Reserve Forest (Patharia Hill) is ~60 km^2, Rajkandi Reserve Forest (Rajkandi) is ~62 km^2, and Tarap Hill Reserve Forest (Tarap Hill) is ~82 km^2 (Fig. 1).

Although all designated as Reserve Forests, the only officially protected area within these four areas is the Rema-Kalenga Wildlife Sanctuary (~17.5 km^2), a small area situated within Tarap Hill. Tarap Hill is also the only patch among our study areas that is not well connected with a greater forested landscape in India. Among the three remaining areas, Atora Hill and Rajkandi Forest are extensions of larger forest tracts in India which expand into Bhutan, and Myanmar. The Rajkandi Forest is

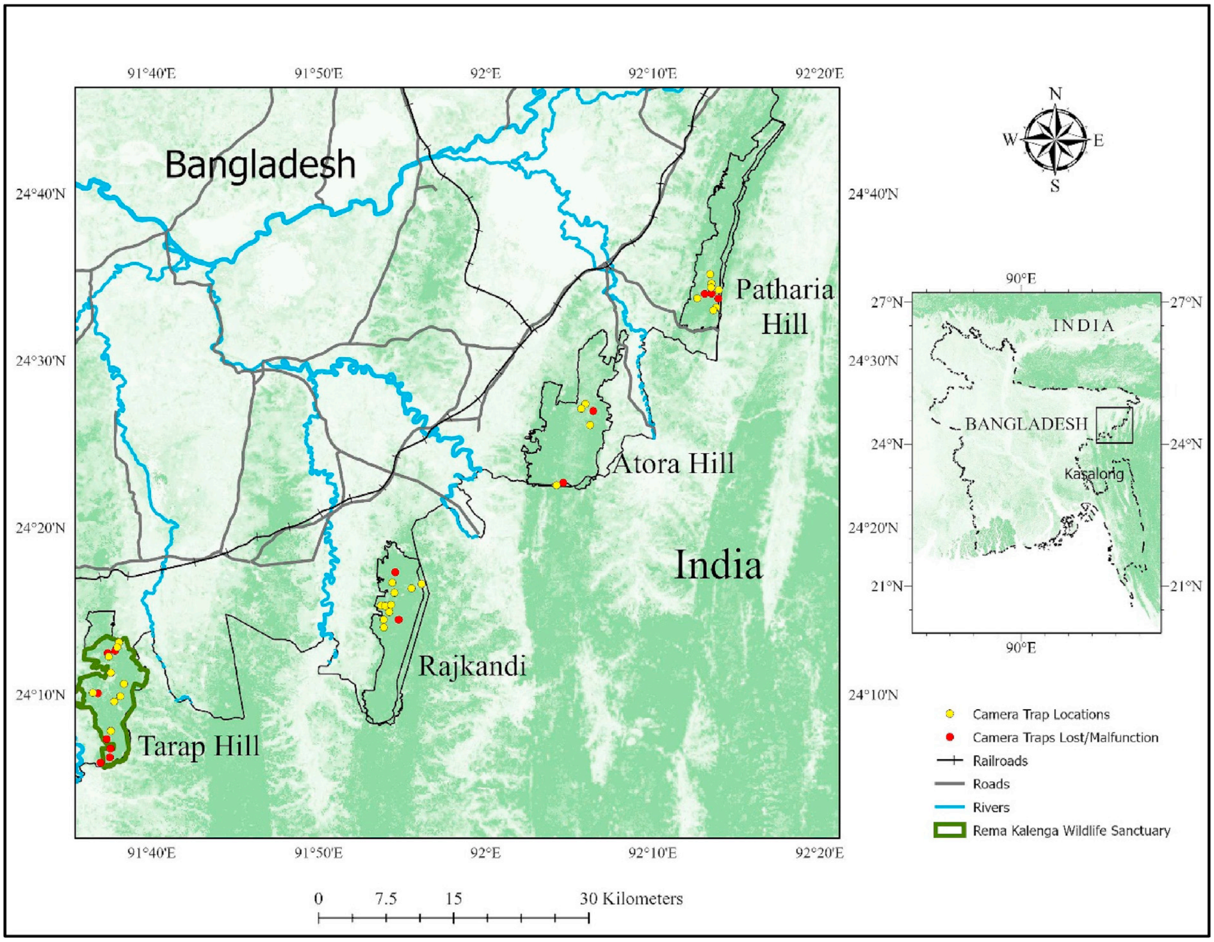

Fig. 1. Camera trap locations in four study areas Atora Hill, Patharia Hill, Rajkandi, and Tarap Hill, in Northeastern Bangladesh.

also connected across India to the Kasalong Reserve Forest, and to the Chittagong Hill Tracts, in Bangladesh. Patharia Hill also has some habitat connectivity with a larger forest complex in India, however geopolitics (building fences at the border) and unplanned development in both countries have reduced that connectivity. Local climate and hydrologic patterns are similar across all four reserve forests, but the disturbance patterns differ (Quazi and Ticktin 2016). Forest composition is also similar, that is mostly semi-evergreen hill forest, generally secondary plantation, and bamboo vegetation, except in Tarap Hill which lacks the mixed bamboo vegetation that is abundant in the other three forest reserves (Bangladesh Forest Department 2012).

3. Methods

Camera trapping: Between May 2014 and January 2015, we operated camera trap stations in the four Forest Reserves: in Atora Hill (n = 6), Patharia Hill (n = 10), Rajkandi (n = 12), and in Tarap Hill (n = 16) camera trap stations; for a total of 128, 311, 400, and 444 trap nights respectively (Table 1).

Table 1
Four study sites in Northeastern Bangladesh, and the dates at which camera trap stations were initiated and completed. The number of effective stations accounts for cameras lost to theft or malfunction, and trap nights is the number of active traps multiplied by the number of days they were active.

Site	Date initiated	Date completed	Num. stations (Num. Effective)	Trap nights
Patharia Hill Reserve Forest	May 1, 2014	June 17, 2014	10 (7)	311
Tarap Hill Reserve Forest	May 30, 2014	Sept. 29, 2014	16 (9)	496
Rajkandi Reserve Forest	Oct. 27, 2014	Jan. 29, 2015	12 (10)	399
Atora Hill Reserve Forest	Dec. 1, 2014	Jan. 27, 2015	6 (4)	128

At each station, we deployed a single camera trap (Bushnell Trophy Cam HD™). To maximize independence for our initial target species (small-medium sized felids), we set trap stations approximately 1.1 km apart (the radius of an estimated minimum home range for leopard cats *Prionailurus bengalensis*) opportunistically throughout the forest fragment. Our camera placement was significantly affected by our ability to access certain regions of the study area, the set number of cameras that we had to conduct the study, and the high number of cameras that were subsequently stolen during deployment. We mounted each camera to a tree, approximately 25–30 cm above the ground, with metal chain, and inside a theft-proof box made of steel. To maximize the capture probability of felids, we used scent-based lures, randomly alternating between either Calvin Klein Obsession for Men (CK Obsession) (n = 36 trap stations), or chicken body parts (n = 8). In some locations we also used an additional visual attractant, i.e. chicken feather (n = 26). Earlier research suggested lures have no negative impact on felid movement (Braczkowski et al., 2016). All of our cameras targeted terrestrial mammals; thus, we acknowledge that the diversity of arboreal species may not be accurately represented by this study. Each camera was active for 24 h per day and programmed to take two photos per trigger event, with a 15-s delay before a subsequent trigger event could occur. Cameras were set to record time and date of each photographs.

Data analysis: We identified each species that was photographed by the camera traps with aid of a comprehensive reference book on mammals of Northeastern India by Anwaruddin Choudhury (2013). We solicited a second opinion from regional mammal experts to identify any questionable photograph. If the identification was not resolved, we did not include it in the analysis. Using this data we then applied a Bayesian MSOM with data augmentation to assess the occupied range of mammal species and species richness (Kéry and Royle 2016). As the actual species richness is unknown, we augmented the dataset with 18 species following Kéry and Royle (2016) and Broms et al. (2016). Published literature differs in terms of mammal species richness in the region, with numbers varying from 20 to 45 (Khan 2008; Feeroz et al., 2011; Chowdhury 2013), we chose the maximum value, following Kéry and Royle (2016). Predicting species richness requires data augmentation, which can be done by adding theoretical species to the model, each of which follow a Bernoulli distribution, this Bernoulli variable indicates whether or not a species occurs in the assemblage of interest (Broms et al., 2016). This enabled us to estimate the potential number of species occurring in Northeastern Bangladesh along with their estimated occupancy. We conducted our statistical analysis in R version 3.4.4 and JAGS (Plummer et al., 2003; R Core Team 2018). We accounted for imperfect detection probability by using a 24-h period as the sampling occasion and recorded all detections of particular species with a 1, or a 0 for no detection, for each sampling occasion. As we had a small number of sample sites, we could not apply co-variates to assess their impact on mammal species richness, community composition, and occupancy probability in Northeastern Bangladesh. We then constructed species accumulation curve from the MSOM model in R, we plotted the species accumulation curve against the number of sampling locations.

We used trap capture rate as an index of relative abundance between study sites. Although the constraints associated with using indices have received much attention (Jennelle et al., 2002; Sollmann et al., 2013), they have received some validation in the context of camera trap studies (Carbone et al., 2001; O'Brien et al., 2003; McCarthy et al., 2010). We have calculated trap detection rates (D) for each species as the number of independent photographs captured of a species (C) per 100 trap nights by using the formula: $D = C \times 100/\sum N$; here $\sum N$ is the total number of camera trap-nights accumulated during the study, accounting for camera loss (due to theft) and or malfunctions. We have considered photos as independent if they were either captured at different trap stations, or if there is more than 30 min between captures of a species at an individual trap station.

4. Results

Initially we set cameras in 44 locations, we lost cameras due to theft in 11 locations, and three additional cameras malfunctioned. This left us with a total of 30 operational camera locations. We accumulated a total of 1283 trap nights throughout the 4 study areas and captured 8692 photographs with animals present. Within these photographs, we recorded 27 mammal species, including human and three domestic or feral species (i.e. domestics dogs, feral and domestic cattle, and feral water buffalo). The 23 wild mammal species consist of 6 orders and 15 taxonomic families (Table 2). We counted 11, 14, 16, and 17 species of wild mammals in Atora Hill, Patharia Hill, Rajkandi, and Tarap Hill respectively.

Estimated occupancy via MSOM ranged between $\Psi = 0.69$ for wild boar (*Sus scrofa*) to $\Psi = 0.10$ for small Indian civet (*Viverricula indica*) with a mean Ψ across species of 0.27 (Table 3).

Only five mammal species were common across all four study areas, the common palm civet (*Paradoxurus hermaphroditus*), northern red muntjac (*Muntiacus vaginalis*), Irrawaddy squirrel (*Callosciurus pygerythrus*), Himalayan crestless porcupine (*Hystrix brachyuran*), and northern pig-tailed macaque (*Macaca leonina*). Unidentified rodents were also present in each area, but due to their smaller size we could not identify them to the species level. There were no species exclusive to Atora Hill, however, Patharia Hill, Rajkandi, and Tarap Hill had three, two, and three exclusive species of mammal respectively. We recorded capped langur (*Trachypithecus pileatus*), elephant (*Elephas maximus*), and ferret badger (*Melogale personata*) only in Patharia Hill; Asiatic jackal (*Canis aureus*) and yellow-throated marten (*Martes flavigula*) were only recorded in Rajkandi Forest; and crab-eating mongoose (*Herpestes urva*), Pallas's squirrel (*Callosciurus erythraeus*), and small Indian civet (*Viverricula indica*) were only recorded in Tarap Hill. Apart from humans and cattle, the mammals recorded on camera most often were Indian muntjac, wild boar, large Indian civet, and Irrawaddy squirrel with total of 76, 69, 66, and 47 independent captures respectively.

Table 2
Species captured by camera trap in four study areas in Northeastern Bangladesh during biodiversity surveys between May 2014 and January 2015.

Order	Family	Common Name	Species	Overall	Number of Independent Photos (Capture rate i.e. number of independent photos per 100 trap nights)			
					Atora Hill	Patharia Hill	Rajkandi	Tarap Hill
Carnivora	Felidae	Asiatic golden cat	*Catopuma temminckii*	4(0.30)	2 (1.56)	0(0)	2(0.50)	0(0)
		Leopard cat	*Prionailurus bengalensis*	9(0.67)	0(0)	3(0.96)	5(1.25)	1(0.20)
	Canidae	Asiatic jackal	*Canis aureus*	1(0.07)	0(0)	0(0)	1(0.25)	0(0)
		Domestic dog	*Canis familiaris*	2(0.15)	0(0)	1(0.32)	0(0)	1(0.20)
	Mustelidae	Ferret badger	*Melogale personata*	1(0.07)	0(0)	1(0.32)	0(0)	0(0)
		Yellow-throated marten	*Martes flavigula*	2(0.15)	0(0)	0(0)	2(0.50)	0(0)
	Viverridae	Common palm civet	*Paradoxurus hermaphroditus*	24(1.80)	9(7.03)	11(3.54)	1(0.25)	3(0.60)
		Large Indian Civet	*Viverra zibetha*	66(4.95)	4(3.13)	0(0)	43(10.78)	19(3.83)
		Masked palm civet	*Paguma larvata*	7(0.52)	0(0)	1(0.32)	0(0)	6(1.21)
		Small Indian civet	*Viverricula indica*	2(0.15)	0(0)	0(0)	0(0)	2(0.40)
	Herpestidae	Crab-eating mongoose	*Herpestes urva*	6(0.45)	0(0)	0(0)	0(0)	6(1.21)
		Mongoose spp.		1(0.07)	0(0)	0(0)	1(0.25)	0(0)
Artyodactyla	Bovidae	Cattle	*Bos Taurus*	126(9.45)	6(4.69)	0(0)	120(30.08)	0(0)
		Water buffalo	*Bubalus bubalis*	23(1.72)	2(1.56)	0(0)	21(5.26)	0(0)
	Cervidae	Northern red muntjac	*Muntiacus vaginalis*	76(5.70)	3(2.34)	21(6.4)	10(2.51)	44(8.47)
	Suidae	Wild boar	*Sus scrofa*	69(5.17)	0(0)	19(6.11)	8(2.01)	42(8.47)
Proboscidea	Elephantidae	Elephant	*Elephas maximus*	3(0.22)	0(0)	3(0.96)	0(0)	0(0)
Rodentia	Hystricidae	Malayan Porcupine	*Hystrix brachyura*	26(1.95)	1(0.78)	6(1.93)	18(4.51)	1(0.20)
	Sciuridae	Pallas's squirrel	*Callosciurus erythraeus*	1(0.07)	0(0)	0(0)	0(0)	1(0.20)
		Particolored flying squirrel	*Hylopetes alboniger*	3(0.22)	2(1.56)	0(0)	0(0)	1(0.20)
		Irrawaddy squirrel	*Callosciurus pygerythrus*	47(3.60)	1(0.78)	2(0.64)	25(5.51)	19(3.83)
	Muridae	Rat spp.		24(1.80)	2(1.56)	6(1.93)	4(1.0)	12(2.42)
Primate	Hominidae	Human	*Homo sapiens*	288(21.59)	11(8.59)	11(3.54)	258(64.66)	8(1.61)
	Cercopithecoidea	Pig-tailed macaque	*Macaca leonina*	27(2.02)	1(0.78)	13(4.18)	11(2.76)	2(0.40)
		Rhesus macaque	*Macaca mulatta*	6(0.45)	1(0.78)	0(0)	2(0.50)	3(0.60)
		Capped langur	*Trachypithecus pileatus*	1(0.07)	0(0)	1(0.32)	0(0)	0(0)
Scandendtia	Tupaiidae	Northern Tree shrew	*Tupaia belangeri*	9(0.67)	0(0)	5(1.61)	0(0)	4(0.81)

5. Discussion

Our study was limited in scope, yet highlights the Northeastern region as an important biodiversity hotspot in Bangladesh. We recorded 23 non-domesticated mammal species in a comparatively small area, including globally threatened species such as Asian elephants. We also recorded Asiatic golden cats that was previously unknown from the region. In addition, the area harbors large array of meso-predators (i.e. two small felids, one canid, four viverrids, two mustelids, and two herpestids), and we must acknowledge that due to our sampling design, the presence of arboreal mammals is likely underestimated. Despite the limitations of our study, compared to similar areas in other countries, Northeastern Bangladesh has been shown to harbor a relatively high mammal diversity in a small area. A study in Namdhapa Tiger Reserve in India recorded only 17 species of mammals in 1985 km^2 area, a study in Huay Khae Khaeg Wildlife Sanctuary in Myanmar recorded 35 mammal species over a 17,373 km^2 area, and a study in Tabin Wildlife Reserve in Malaysia recorded 26 mammals (Datta et al., 2008; Bernard et al., 2014; Naing et al., 2015). This indicates the importance of protecting the remaining forested patches in Bangladesh in order to protect this crucial biodiversity.

The MSOM model showed that we did not reach asymptote in terms of sampling locations (Fig. 2) and the model predicted a total of 37 species of mammal occurring in Northeastern Bangladesh. Our camera traps failed to record some species that are have been definitively recorded in the region either by a previous study or one conducted subsequent to ours. These species include: the jungle cat (*Felis chaus*), fishing cat (*Prionailurus bengalensis*), marbled cat (*Pardofelis marmorata*) Asiatic wild dog or dhole (*Cuon alpinus*), Chinese pangolin (*Manis pentadactyla*) and Asiatic black bear (*Ursus thibetanus*) (Feeroz et al., 2011; Muzaffar et al., 2011; Khan 2015; Zakir et al., 2020; Ghose et al. in preparation). In addition, owing to the scope of our study and the focus upon terrestrial species, we did not accurately sample arboreal and semi arboreal species know to inhabit the region such as: the Malayan giant squirrel (*Ratufa bicolor*), Phayre's leaf monkey (*Trachypithecus phayrei*), and Bengal slow loris (*Nycticebus bengalensis*) (Khan 2008; Feeroz et al., 2011; Chowdhury 2013; Al Razi et al., 2020). Moreover, two species were captured by local people in Atora Hill and taken into custody by the Bangladesh Forest Department; a fishing cat and a red serow (*Capricornins rubidus*) (Rahman et al., 2014; Rahman and McCarthy 2014). This confirms their presence in the area, yet those species were not recorded by our camera traps.

Protected areas are a crucial means to conserve wildlife from habitat loss and other anthropogenic stressors. However, the protected area network can be ineffective if poorly designed (Hoffmann et al., 2010). Although all are considered Forest Reserves, the only officially protected area among our study sites is Rema-Kalenga Wildlife Sanctuary (Rema-Kalenga), part of Tarap Hill. Our findings suggested that Rema-Kalenga supported more species of wild mammals than the other forest reserves, and has minimal human disturbance (e.g., there were no cattle or human photographed during the survey). Yet, at only

Table 3
Estimated occupancy and probability of detection for each recorded species in the region along with 95% CI.

Common name	Species	Sites Detected	Mean ψ	95% CI	Mean P	95% CI
Wild boar	*Sus scrofa*	19	0.69	0.49–0.87	0.06	0.05–0.08
Human	*Homo sapiens*	21	0.66	0.49–0.82	0.15	0.13–0.18
Red muntjac	*Muntiacus vaginalis*	18	0.63	0.44–0.81	0.08	0.06–0.09
Large Indian civet	*Viverra zibetha*	14	0.47	0.29–0.65	0.09	0.07–0.11
Irrawaddy squirrel	*Callosciurus pygerythrus*	12	0.4	0.24–0.58	0.07	0.05–0.1
Leopard cat	*Prionailurus bengalensis*	6	0.38	0.14–0.78	0.02	0.01–0.04
Pig tailed macaque	*Macaca leonina*	10	0.38	0.2–0.6	0.05	0.03–0.07
Cattle	*Bos taurus*	10	0.32	0.17–0.49	0.16	0.12–0.2
Rat spp.		8	0.31	0.15–0.53	0.05	0.02–0.07
Rhesus macaque	*Macaca mulatta*	4	0.3	0.08–0.74	0.02	0–0.04
Asian palm civet	*Paradoxurus hermaphroditus*	8	0.29	0.14–0.48	0.06	0.03–0.09
Himalayan crestless porcupine	*Hystrix brachyura*	7	0.26	0.12–0.44	0.06	0.04–0.09
Masked palm civet	*Paguma larvata*	4	0.26	0.07–0.61	0.02	0.01–0.05
Northern tree shrew	*Tupaia belangeri*	4	0.23	0.07–0.53	0.03	0.01–0.06
Yellow throated marten	*Martes flavigula*	2	0.22	0.03–0.7	0.01	0–0.04
Domestic dog	*Canis familiaris*	2	0.21	0.03–0.69	0.02	0–0.05
Pallas's squirrel	*Callosciurus erythraeus*	1	0.16	0.01–0.61	0.01	0–0.05
Capped langur	*Trachypithecus pileatus*	1	0.14	0.01–0.57	0.02	0–0.07
Golden jackal	*Canis aureus*	1	0.14	0.01–0.56	0.02	0–0.07
Asiatic golden cat	*Catopuma temmickii*	2	0.13	0.02–0.37	0.03	0.01–0.08
Crab eating mongoose	*Herpestes urva*	2	0.13	0.02–0.36	0.03	0.01–0.06
Mongoose spp.	*Herpestes* spp.	1	0.13	0.01–0.56	0.02	0–0.07
Particolored flying squirrel	*Hylopetes alboniger*	1	0.12	0.01–0.53	0.03	0–0.12
Water buffalo	*Bubalis bubalis*	3	0.11	0.03–0.25	0.09	0.05–0.15
Asian elephant	*Elephas maximus*	1	0.1	0.01–0.37	0.03	0–0.09
Ferret badger	*Melogale personata*	1	0.1	0.01–0.37	0.03	0–0.09
Small Indian civet	*Viverricula indica*	1	0.1	0.01–0.38	0.03	0–0.08

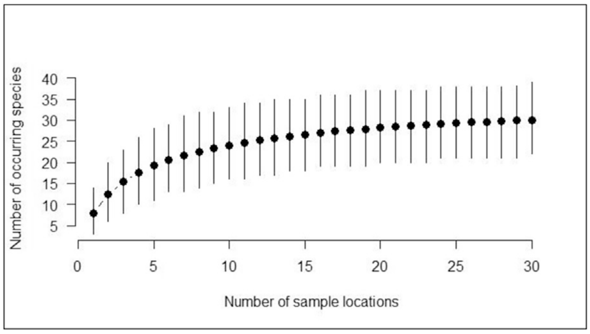

Fig. 2. Species accumulation curve for mammal species across four study sites, Atora hill reserve forest, Patharia hill reserve forest, Rajkandi reserve forest, and Tarap hill reserve forest.

17.5 km^2 in size, this protected area is inadequate to effectively harbor any medium or large-ranging species, with even small felids like the Asiatic golden cat (*Catopuma temminckii*) having a home range of around 30 km^2, similarly, leopard cats need around 12–14 km^2 area, and large India civets require around 12 km^2 (Rabinowitz 1991; Grassman et al., 2005a, 2005b; McCarthy et al., 2015). Which suggests persisting and thriving populations of even such mesopredators would need larger protected areas.

In addition to protected status, connectivity between forested patches can have an impact on fragment-level biodiversity in relation to species persistence and recolonization (Fahrig and Merriam 1985, 1994). For species that are rare and restricted in the types of habitat through which they can disperse, connectivity is of primary importance and must be considered in management decisions. Atora Hill and Rajkandi have higher levels of connectivity with the Manas-Namdhapa Tiger Conservation Landscape in India, and we recorded Asiatic golden cat at both sites, but not in the other forest patches where connectivity is low. This suggests that maintaining the current connectivity to the forested areas in the Manas-Namdhapa Tiger Conservation Landscape may be important to the continuing existence of certain mammal species in Northeastern Bangladesh, although increased protection within the forest patches is necessary to avoid the area acting as a population sink.

The third factor that is likely affecting biodiversity in the forest patches of Northeastern Bangladesh is the presence of human stressors. These human stressors come in the form of resource extractions within the forest (gathering of betel leaf, bamboo, etc.), tribal villages within the managed forests and their free-ranging cattle, and the surrounding anthropogenic habitats of villages, plantations, and industry. It is suggested that forested areas in the tropics which are surrounded by a larger proportion of anthropogenic habitats, host mammal communities with lower species richness and lower species diversity (Ahumada et al., 2011). However, mesopredators, especially those with omnivorous feeding habits, might be well accustomed to the high human disturbance and thrive in absence of the larger predators. Indeed, we found that mesopredators such as large Indian civet, small Indian civet, masked palm civet (*Paguma larvata)*, common palm civet (*Paradoxurus hermaphroditus)*, leopard cat, and mongoose spp (*Viverrid* spp.*)* were present across Northeastern Bangladesh. Although mesopredators were somewhat common, our results suggest that there are not many species with large home range requirements left in the region, except elephants, which use the landscape between Bangladesh and India. Nevertheless, water buffalo (*Bubalis bubalis*) in Atora Hill and Rajkandi Forest are domesticated buffalo that uses the forest for grazing, those of the camera trapping sites we have recorded buffalos are very close to the village.

Although it is evident that anthropogenic stressors in Northeastern Bangladesh are affecting the availability of habitat in the region, it remains an important source of biodiversity within the country. The data from this study provides important insight into targets for conservation strategies that may promote the conservation of biodiversity for the long-term. Currently, only the 17.5 km^2 Rema-Kalenga Wildlife Sanctuary is officially protected, and this forest harbors some of the only large mammals that we recorded during this study. Expanding the officially protected forest status to a larger area may lessen anthropogenic stressors in these areas and promote the maintenance of habitat for large mammals. Furthermore, it is imperative to prioritize protection of areas with better connectivity to large forested reserves. Our results suggest that Rajkandi hosts almost same diversity of mammals as Tarap Hill, despite being smaller in size, and experiencing much higher levels of anthropogenic pressure. This may be due to the connectivity with the larger forested landscape across the border in India. Connectivity between forested patches is very crucial to sustain wildlife populations over a longer period, allowing for gene flow and dispersal (Powell 2012). If protection is ensured throughout the entire 60 km^2 area of Rajkandi, it will help ensure that that forest fragment does not become a sink population for species moving across the border from India. In addition, recent studies have shown the utility of even small forest fragments in encouraging connectivity between forest fragments in an anthropogenic landscape (Weiskopf et al., 2019). Thus, the tea gardens, rubber plantation, homestead forests, bamboo grove, and swamps of the Northeastern region may play an important role in facilitating connectivity in the region. We suggest further in-situ research should be conducted to explore this potential.

In conclusion, our study provided baseline information on mammal species richness and community composition in the Northeastern Bangladesh. We also highlight areas that should be prioritized for conservation action. This will enable managers to make informed decisions in the future that will help to protect species diversity in this important region of Bangladesh. Moving forward, Bangladesh has the potential to play an important role in landscape-level conservation initiatives in the region, contributing to the larger landscape of the Manas-Namdhapa Tiger Conservation Landscape.

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.

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