Seasonal Ranging Pattern of Asian Elephants in the Protected Area Landscape of Bangladesh

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Abstract

Background

Seasonal ranging pattern of the Asian Elephants was assessed within two major Protected Areas, namely Chunati Wildlife Sanctuary and Teknaf Wildlife Sanctuary situated in the southern Bangladesh, for the period between November 2016 and May 2018. The objective of this study was to see how do the elephants move across the Protected Area landscapes, what was the linkage between the water sources and elephant's seasonal movement patterns and how does vegetation cover link to elephant movement.

Methods

The ranging pattern was analyzed using the elephant dung distribution data. Normalized Difference Vegetation Index and Normalized Difference Water Index were estimated through satellite image analysis.

Results

Study clearly indicated that the ranging pattern of elephants fully depends on the vegetation and water sources. The areas where water sources and vegetation coverage were good, elephant movement was higher. The study identified few areas of these two Protected Areas where both vegetation coverage and water sources were visible and those areas as hot-spots for elephants.

Conclusions

The findings of this study can be used in conservation and management of elephants, particularly through the protection of preferred water sources and vegetation covered areas. In future these areas need to be protected and take proper management interventions.

Background

The Asian Elephant is the largest living land mammal (Gopalakrishna et al. 2010) and is presently endangered (Choudhury et al. 2008). There are only around 50,000 elephants in the wild and another 16,000 in captivity distributed across 13 Asian countries today (Sukumar, 1989a). In Bangladesh, Asian Elephants are considered as 'Critically Endangered' species (IUCN Bangladesh, 2015) and elephants occur in 7 fragmented forest divisions of Bangladesh (IUCN Bangladesh, 2016). All elephant populations are considered vulnerable to continuing habitat loss from large-scale habitat conversion resulting from agriculture, unplanned development interventions, human settlement, illegal logging, etc. (Ministry of Environment and Forests, 2018). This has resulted in compression of elephant herds in Protected Areas causing escalation of human elephant conflict in the adjoining human-dominated landscapes (Desai, 1991). Landscape variables such as spatial heterogeneity in vegetation cover (Murwira and Skidmore,

2005), seasonal change in resource availability (Santiapillai et al. 1984), and human density (Buij et al. 2007; and Hoare and Du Toit, 1999) influence elephant distribution and use of natural and man modified habitats, and patterns of human elephant conflict and encounters (Singh et al. 2002; and Nyhus et al. 2000). Close and frequent encounters between humans and elephants in landscapes with settlements and croplands have detrimental effects on long-term conservation of elephants (Fernando et al. 2005). As a result of fragmentation and the ensuing interspersion of human habitation, cultivation, and natural habitats, conflicts between humans and elephants are now widespread across Africa (Dublin and Hoare, 2004; Hoare, 1999; and Thouless, 1994) and Asia (Madhusudan, 2003; Sukumar, 1989; and Blair et al. 1979). In such situations, understanding the relationships between landscape elements such as human habitations, habitat remnants, and elephant activity is an important area of research (Hoare, 1999).

Elephants require sufficient food, suitable shelter, sufficient water, and healthy habitat conditions to survive (Kar et al. 2016; and Zimmermann et al. 2009). Considering these requirements, elephants are in enormous danger led by habitat loss and fragmentation, food shortage, and direct killing; together these are seriously impacting the Asian Elephant population in Bangladesh (Ministry of Environment and Forests, 2018). The distribution of food resources for mega-herbivores in natural environment is not homogeneous and the distribution is influenced by an interacting factor, which includes topography, elevation, soil type, amount of rainfall, and human interference (Provenza, 2008; and Pomeroy and Service, 1992). In addition, seasonal change in the distribution of food resources has impact on spatial structure, demography, and movement patterns in mega-herbivores (Turchin, 1998), including elephant (Wittmyer et al. 2007). As a result, for meg-herbivores to maximize food resources intake, they have to move from one area to another within the landscape (Prains and van Langevelde, 2008). Because of huge dietary requirements, elephants extensively search for food, water, and shelter within a particular habitat or other habitats. During the early wet season, elephants are scattered throughout forested areas, when food and water are available. The quality of habitat and resources begin to depreciate during the summer season, and then the elephants look for and move to the other habitats where food and shelter are available (Varma, 2013).

Before starting any development activities within or near forest areas or elephant habitats, it is important to know the elephant movement routes and corridors for the conservation of this mega species. A knowledge of elephant movements can answer a wide range of questions relevant to their general ecology and thereby to their long-term conservation and management (Whyte, 1996). Knowledge on how animals move in their environment can give critical insight into animal's behavior that may be used in the effective management and conservation of species under study. The main objective of the present study was to assess the seasonal ranging pattern of wild elephants within two Protected Areas of the country namely, Chunati Wildlife Sanctuary and Teknaf Wildlife Sanctuary, a core habitat of Asian Elephants of South Eastern Bangladesh. This study aimed at answering the following research questions: a) how does elephant move across the protected area landscapes? b) what is the linkage between the water sources and elephant’s seasonal movement patterns? and c) how does vegetation cover link to elephant movement?

Methods

Study area

The study was conducted in two Protected Areas of southeastern part of Bangladesh, namely Teknaf Wildlife Sanctuary (TWS), and Chunati Wildlife Sanctuary (CWS): only MIKE (Monitoring the Illegal Killing of Elephants) site of Bangladesh. Figure 1 showed the location of the two study sites.

CWS, IUCN category IV: a Protected Area managed mainly for the sustainable use of natural ecosystems (IUCN, 1994), was declared as wildlife sanctuary by gazette notification on 18 March 1986 with an area of 7763.97 hectare (Bangladesh Forest Department, 2020). It is located at 21°48" to 22°05" N and 91°57" to 92°07" E, 70 km from the Chittagong City and under the management of Chittagong Wildlife and Nature Conservation Division. Chunati belongs to the tropical evergreen and semi-evergreen forest biogeographic zone, representative of the biodiversity of the southeastern region of the country, with hilly to mountain areas ranging from 30–90 meters in elevation. This area is gradually denuded due to human settlement, illicit felling and conversion of land for cultivation. CWS is fallen under two forest ranges (Chunati and Jaldi) and 7 forest beats (Aziznagar, Chunati, Harbang, Puichari, Napura, Jaldi, Chambal) (Feeroz, 2014). Chunati Wildlife Sanctuary is familiar as the habitat and breeding ground of the Asian Elephant. It is one of the oldest PAs of Bangladesh which is rich with 691 plants from all habit forms (Hossain and Hossain, 2014). In addition to the Asian Elephant, Chunati harbors 26 species of amphibians, 54 reptiles, 252 birds, and 40 mammals (Feeroz, 2014).

TWS, IUCN category VI: a Protected Area managed mainly for the sustainable use of natural ecosystems (IUCN, 1994), was declared as wildlife sanctuary by gazette notification on 9 December 2009 with an area of 11614.57 hectare (Bangladesh Forest Department, 2020). It is located in the southeastern corner of Bangladesh (20°52" to 21°04" N and 92°08" to 92°18" E), 450 km from the capital city Dhaka. It lies between the Naf river on the eastern side and Bay of Bengal on the western side. TWS covers 10 forest beats in three forest ranges (Whykheong, Shilkhali and Teknaf) of Cox's Bazar South Forest Division (Feeroz, 2013). TWS consists of a linear hill range extended from north to south, gently inclined to uneven hills and cliffs running down the central part of the peninsula. The range has several undulating projections running towards east and west and interspersed by valleys, gullies and crossed by 149 seasonal streams. The area is very unique and covers diverse ecosystems including hill forest, mangrove vegetation and sand dune ecosystem (Cannonizado, 1999; and Ghani, 1950).

Climatic Features

Based on the climatic conditions, the study regions are characterized with distinct dry and wet seasons (Fig. 2 and Fig. 3). The average precipitation and average temperature of Chittagong South Forest Division and Cox's Bazar South Forest Divisions for last 30 years were shown in the Climograph. In this study, we considered both dry and wet season to show seasonal differences for the CWS and TWS.

Data Collection

Elephant dung sample

According to Motaleb et al. (2016), a reconnaissance survey was conducted along the elephant movement routes of CWS and TWS to familiarize the sites. Local forest department officials and the local communities were also consulted (through Focus Group Discussions and one to one discussions) and fixed the elephant trails. Field survey was conducted from November 2016 to May 2018. On each elephant movement trails elephant dung samples were marked and recorded using GPS. The seasonal variations were investigated by collecting data of two different seasons (Dry season: November to March; and Wet season: April to October). On a given day, planned elephant trails were walked by survey teams comprised of local Bangladesh Forest Department (BFD) staff, local guide and trained volunteers and took notes of GPS locations of the elephant dungs on a structured questionnaire.

Satellite imagery

In this study, Sentinel-2A datasets were used for image analysis. These datasets were obtained from USGS earth explorer portal considering cloud free conditions for performing vegetation index and water index estimation. The projection for all image datasets was received in World Geodetic System 1984 (WGS 84) Universal Transverse Mercator (UTM) zone 46N. The sources and datasets used in this study are given in Table 1.

Table 1
Description of the satellite image data used in this study

Season	Satellite data	Acquisition date	Sensor resolution	Source
Dry	Sentinel-2A	February 2017	10 m, 20 m and 60 m in Visible and Near Infrared (NIR) to Short-Wave Infrared (SWIR) spectral range	USGS Earth Explorer
Wet	Sentinel-2A	October 2017	10 m, 20 m and 60 m in Visible and Near Infrared (NIR) to Short-Wave Infrared (SWIR) spectral range	

Data analysis

Dung distribution pattern and route mapping

Spatial layers of dung and route were generated using Geographic information system in QGIS 2.18 environment that helped in mapping dung distribution pattern and movement route. Elephant dung density was shown in Heat Map, where kernel density estimation method was followed. Heat Map plugin

was used to generate dung density map for dry and wet season for both PAs where elephant dung layer was used as input layer.

Pre-processing of satellite data

In order to get better estimation from image analysis, top-of-atmosphere (Level-1C) reflectance was converted into surface reflectance (Level-2A) for all images. This processing has been done through using Semi-automatic classification plugin in QGIS 2.18.

Image analysis: Normalized Difference Vegetation Index (NDVI)

One of the main focuses of this study was to identify linkages between elephant movement and vegetation cover presence. The NDVI is an important classification method which is helpful to quickly identify vegetated areas with the use of multispectral remote sensing data. Besides, NDVI has a proven track of record in predicting wild animal's distribution and abundance in space and time (Pirotti et al. 2014). Thus, we considered the estimation of this index in our study. For the estimation of NDVI, Sentinel-2A satellite data was used in this study. The NDVI was computed as:

$$NDVI = \frac{(NIR - RED)}{(NIR + RED)}$$

Where, NIR and Red are the amount of near-infrared and red light, respectively, which is reflected by a surface and analyzed by satellite sensors (Pettorelli et al. 2011).

The value of NDVI varied between − 1.0 and + 1.0. The healthy vegetation has low red-light reflectance and high near-infrared reflectance that produce high NDVI values. The mounting amount of the positive NDVI values indicates the increase in the amounts of green vegetation. The NDVI values near zero and decreasing negative values indicate non-vegetated features, such as barren surfaces (rock and soil), water, snow, ice, and clouds (Saravanan et al. 2019). In other way, very low values of NDVI (0.1 and below) correspond to barren areas of rock, sand, or snow. Moderate values represent shrub and grassland (0.2 to 0.3), while high values indicate temperate and tropical rainforests (0.6 to 0.8) (Weier and Herring, 2000).

Image analysis: Normalized Difference Water Index (NDWI)

The information about the presence of water bodies in a particular landscape could be derived through using NDWI. In this study, one of the objectives was to see the elephant seasonal movement patterns in relation to water sources. Thus, NDWI was estimated using Sentinel-2A satellite data in QGIS environment. The index was proposed by McFeeters (1996) as follows:

$$NDWI = \frac{(Green - NIR)}{(Green + NIR)}$$

Index values greater than 0.5 usually correspond to water bodies. Vegetation usually corresponds to much smaller values and built-up areas to values between zero and 0.2.

Results

Seasonal movement across Protected Area landscape

At Chunati Wildlife Sanctuary

Study exposed that in CWS elephants route network were distributed all the forest beats in both dry and wet seasons. GIS analysis was done to assess elephant's movement pattern, including their movement routes and feeder routes, within each forest beats. Beat wise elephants' movement of CWS was presented in Table 2.

Table 2
Forest Beat wise elephants' movement (in kilometer) in Chunati Wildlife Sanctuary

Season	Forest Beat	Distance travel (Kilometer)
Dry season	Puichari	28.82
	Chunati	20.65
	Napura	19.33
	Jaldi	17.39
	Harbang	16.74
	Chambal	15.57
	Satgar	05.85
Wet season	Harbang	23.70
	Napura	16.92
	Chunati	14.98
	Chambal	12.46
	Puichari	11.36
	Jaldi	05.07
	Satgar	04.29

Based on dung distribution, elephant's movement patterns across all the forest beats of CWS for dry and wet season was shown in Fig. 4.

From the study it was observed that the elephant dungs were distributed in clustered and scattered pattern in dry and wet season respectively that showed that elephant use all the seven forest beats of CWS. In dry season, the number of dung piles were found highest in Jaldi forest beat (653); followed by Puichari (202), Chunati (104), Harbang (92), Chambal (70) and Napura (62). However, in wet season, the number of dung piles were found highest in Chunati forest beat (447); followed by Napura (339), Jaldi (234), Puichari (220) and Chambal (98). In both dry and wet seasons, it was observed that the number of dung piles were higher in Jaldi, Puichari and Chunati of CWS.

At Teknaf Wildlife Sanctuary

Study exposed that in TWS elephants route network were distributed all the forest beats in both dry and wet seasons. GIS analysis was done to assess elephant's movement pattern, including their movement routes and feeder routes networks, within each forest beats. Beat wise elephants' movement of CWS was presented in Table 3.

Table 3
Forest Beat wise elephants' movement (in kilometer) in Teknaf Wildlife Sanctuary

Season	Forest Beat	Distance travel (Kilometer)
Dry season	Mochoni	32.98
	Madhya Nhila	27.36
	Teknaf	19.00
	Rajarcchora	17.92
	Raikhiyong	14.09
	Nhila	11.81
	Shilkhali	10.73
	Shamlapur	9.50
	Mathabhanga	7.24
Wet season	Teknaf	25.04
	Raikhiyong	23.66
	Madhya Nhila	20.79
	Mochoni	20.36
	Shamlapur	20.24
	Rajarcchora	16.56
	Mathabhanga	11.71
	Shilkhali	11.66
	Nhila	3.25

Based on dung distribution, elephant's movement patterns across all the forest beats of TWS for dry and wet season was shown in Fig. 5. From the study it was observed that the elephant dungs were distributed in scattered and clustered pattern in dry and wet season respectively that showed that elephant use all the nine forest beats (Table 3) of TWS.

In dry season, the number of dung piles was highest in Mochoni forest beat (415); followed by Teknaf (309), Nhila (170), Madhya Nhila (139), Mathabhanga (88), Shilkhali (84) and Rajarcchora (69) forest beat. However, in wet season, the number of dung piles were highest in Mochoni forest beat (313);

followed by the Shamlapur (214), Raikhyiong (119), Mathabhanga (117), Teknaf (110), Nhila (70), Madhya Nhila (61), and Rajarchora (55) forest beat. Both dry and wet season data showed that the elephant movement was higher in Mochoni, Teknaf, and Shamlapur forest beats.

Elephant Movement In Relation To Water Sources

At Chunati Wildlife Sanctuary

The linkage between seasonal elephant movement with water sources was illustrated through water index map (Fig. 6) that depicted that the elephant movement pattern had seasonal contrasts in water distribution. NDWI map showed that CWS was characterized with only few stream networks. Whereas, water bodies (except the streams) were distributed across the whole Protected Areas which were located along the boundary areas covering Harbang, Chunati, and Satgar forest beats and less water bodies were observed in Jaldi, Chambal, Napura and Puichari.

From the study it was found that the elephant movement was closely related to the distribution of water bodies across all forest beats. Figure 6a showed the elephant movement pattern in relation to water sources during the dry season across all forest beat of CWS. It was clearly evident that the elephant movement (represented by elephant dung) was intense close to water bodies in all forest beat, with more concentration in Chunati, Puichari, Harbang and Jaldi. The same analysis was done for the wet season and represented in the Fig. 6b. In wet season, the similar observation was found as dry season in terms of water bodies distribution in Chunati, Satgar and Harbang forest beat which indicated the presence of permanent water bodies inside the Protected Areas. Inset map depicts that elephant dung density was higher in Chunati and Napura forest beat due to the presence of bigger water bodies in wet season. For both dry and wet seasons, the dung density for Jaldi showed higher but not any water sources observed in the map. During the field survey it was found that water sources were present adjacent to the Jaldi beat which is outside the current study area.

At Teknaf Wildlife Sanctuary

Figure 7 depicted the elephant movement in relation to water resources during the dry and wet season across all forest beats of TWS. It was evident from water index map of both seasons that the elephant movement pattern has seasonal dissimilarities in water source distribution like CWS. From the map, it was evident that TWS was attributed with a rich network of several streams almost in all forest beat areas. NDWI map (Fig. 7a and 7b) showed the wide distribution of water bodies across the whole Protected Area.

Figure 7a showed the elephant movement pattern in relation to water sources during the dry season across all forest beat of TWS. All forest beat was characterized with the presence of rich stream network. From the inset map, it can be clearly seen that elephant dung density layer overlapped with stream layer in Teknaf forest beat. This indicates a relationship between the presence of elephant and the stream or water sources. Elephants' intense movement along the stream were observed in Mathabhanga, Rajarcchora, Teknaf, Mochoni, Nhila, Madhya Nhila and Shilkhali forest beat of TWS.

Elephant movement pattern linked to stream network during the wet season was mapped and represented in the Fig. 7b. Similar observation as in dry season was found in terms of stream network

distribution across all forest beats of TWS. Study revealed higher elephant dung density along the stream network in Shamlapur, Raikhiyong, Mathabhanga, Rajarcchora, Teknaf, Mochoni and Nhila forest beat of TWS. Study clearly indicated that Mathabhanga, Rajarcchora, Teknaf, Mochoni, Nhila, Shamlapur, and Raihiyong Madhya Nhila and Shilkhali are very important forest beats for elephants due to the presence of water sources.

Linking Vegetation Index To Movement Pattern

At Chunati Wildlife Sanctuary

Figure 8 illustrated the elephant movement pattern, overlaid on a NDVI map, during the dry and wet season across all forest beat of CWS. During the dry season, NDVI values ranges from 0.45 to 0.85 which indicates the presence of grassland, shrub land and forested areas across the whole Protected Area landscape. NDVI map showed the status of the presence of green vegetation CWS for dry season (Fig. 8a). From NDVI map it can be seen that rich vegetation with higher NDVI values had scattered distribution with patch type pattern. Jaldi, Chambal, Napura, Puichari and Chunati forest beat had good coverage of rich vegetation in comparison to Harbang and Satgar beat. Elephant higher dung density distribution was concentrated to those areas with rich vegetation. Elephant dung distribution similarly showed cluster type pattern in those rich vegetation areas.

In contrast, different observation was found in terms of elephant movement and vegetation coverage during the wet season in CWS (Fig. 8b). In wet season, NDVI value range (0.47 to 0.89) was a little higher than that in dry season. During this season, all forest beat had good coverage of rich vegetation with higher NDVI values due to the seasonal precipitation as expected. In this case, elephant dung density was more concentrated in the Chambal, Napura, Puichari and Chunati forest beat with wider movement. From the NDVI it clearly indicated that elephant movement has positive relationship with the vegetation cover and where there was rich vegetation the elephant movement was higher.

At Teknaf Wildlife Sanctuary

Figure 9 showed the elephant movement pattern, overlaid on a NDVI map, during the dry and wet season across all forest beat of TWS. During the dry season, NDVI values ranges from 0.23 to 0.70 which indicates the presence of grassland, shrub land and forested areas across the TWS landscape. NDVI map showed the status of the presence of green vegetation of TWS for dry season (Fig. 9a). From NDVI map it was observed that rich vegetation with higher NDVI values had scattered distribution with patch type pattern in TWS. Raikhiyong, Mathabhanga, Rajarcchora, Teknaf and Mochoni forest beat had good coverage of rich vegetation in comparison to Shamlapur, Shilkhali and Nhila beat. Elephant higher dung density distribution was concentrated to those areas with rich vegetation. Elephant dung distribution also showed cluster type pattern within all beat areas except Nhila beat where directional movement was observed.

Unlike dry season, elephant movement and vegetation coverage showed different pattern across the TWS beat areas in the wet season (Fig. 9b). During the wet season, NDVI value ranged from 0.26 to 0.85 that was higher in comparison to the dry season. During this season, almost all forest beat had good coverage of rich vegetation with higher NDVI values due to the seasonal precipitation as expected. During this season, elephant movement was so intense across all forest beat areas with cluster type distribution. Even though rich vegetation was available across the whole Protected Area landscape, however, elephant movement was concentrated in some part of the beat areas following connectivity with other beat.

Discussion

Availability of food, water, as well as climate and seasons determine the extent of an elephant's movement throughout their home range. Typically, during the dry winter months (January-April) Asian Elephants reside in river valleys. At the onset of monsoon, they begin their long-term migration towards upper slopes in some of the areas (Joshi and Singh, 2008). Their day-to-day movement and resting patterns tend to fluctuate during monsoon due to restricted mobility. During the first part of the wet season (May-August) they reside in tall grass forests. Over the second part (September-December) they move to open forests with short grass cover (Sukumar, 1989). In summer, elephants move more as they have to travel in search of food and water, due to lack of fodder species and shrinkage of natural water sources (Joshi and Singh, 2008).

From the current study it was clear that elephant's movement was distributed in all the forest beats of the Protected Areas both in dry and wet seasons. In dry season, the forest coverage was become less in both TWS and CWS, but the opposite scenario was in dry season. The NDVI and NDWI maps showed that elephant's movement was strongly related with the availability of water sources and vegetation coverage. Where water availability and vegetation coverage were high the dung concentration was also high which indicated the elephant's presence. Compared to the CWS, TWS had more stream networks i.e., water availability was higher and accordingly elephant's presence were observed all over TWS.

Alfred et al. (2012) conducted a study at Sabah, Malaysia and found that the ranging behavior of Asian Elephants was influenced by the size of the natural forest habitat and the availability of permanent water sources. Also, their movement pattern was influenced by human disturbance and the need to move from one feeding site to another. Neupane et al. (2019) conducted a study at Bardia National Park, Nepal and concluded that elephant's habitat preference was mainly associated with food resources such as grassland or mixed forest. Another study held at Nilgiri Biosphere Reserve of Southern India also revealed that the dry season movements of elephants were restricted around the perennial water sources, while the wet season movements were extended to areas with temporary water sources (Baskaran et al. 2018). Wato et al. (2019) found that elephant's movement patterns showed a stronger directional orientation toward water sources in the dry season compared to the wet season. A similar study was conducted by Bohrer et al. (2014) at Kenya and observed that the elephants respond quickly to changes in forage and water availability, making migrations in response to both large and small rainfall events.

IUCN Bangladesh (2016) found significant number of elephant's presence in and around the CWS and TWS. Also, a number of elephant movement corridors were also present close to these Protected Areas (Motaleb et al. 2016). Considering elephant's presence and their significance for the environment proper management needs to be taken to protect these water sources and the vegetation coverage of these two important Protected Areas of the country.

Conclusions

The Asian Elephant (*Elephas maximus*) is a keystone species playing an important role in maintaining and balancing the structure of an ecological community and affecting many other organisms within the ecosystem. It has ingrained in our culture and the importance of conserving the Asian Elephant in Bangladesh is now established. Considering its significance for environment and future, thorough research is being carried out globally, but in Bangladesh the comprehensive research is still in the early stage and mostly related to the elephant population, human-elephant conflict. But no precise study has been conducted so far to understand the exact ecological behavior of wild elephants in Bangladesh which made difficult in determining the precise degree of their threats. Current study has assessed the ecological behavior of the Asian Elephant in the southern part of Bangladesh. Study revealed that elephant's movement has close relationship with the availability of vegetation coverage and water sources. The area where the water and vegetation coverage were higher, the elephant movement was higher. The study clearly indicated that the Chunati Wildlife Sanctuary and Teknaf Wildlife Sanctuary are two important elephant habitat of the country and for conservation of the elephants both vegetation and water sources of these two Protected Areas needs to be protected. Findings of the study will help the forest managers to take proper management interventions for conserving this flagship species. The present investigation also paved the way for further ecological study of Asian Elephant's in Bangladesh and global arena.

Declarations

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Authors' contributions

This manuscript is part of the PhD work of MAM, supervised by MMHK. MAM, MSA, MAAM, MMHK and AAM have significantly contributed in the concept development, working methodology development, field work, literature review, data cleaning, sorting and analysis, and manuscript writeup. On top of that, AH,

MAR, SS, SC, MRH, RAA, MZUF, MAR and MEA were mainly involved in field data collection, data cleaning, data soring and literature review. All authors read and approved the final manuscript.

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Availability of data and materials

The datasets used and/or analyzed during the current study are available from the corresponding author on reasonable request.

Ethics approval and consent to participate

No ethical issues arose in this work.

Consent for publication

Not applicable.

Competing interests

The authors declare that they have no competing interests.

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Figures

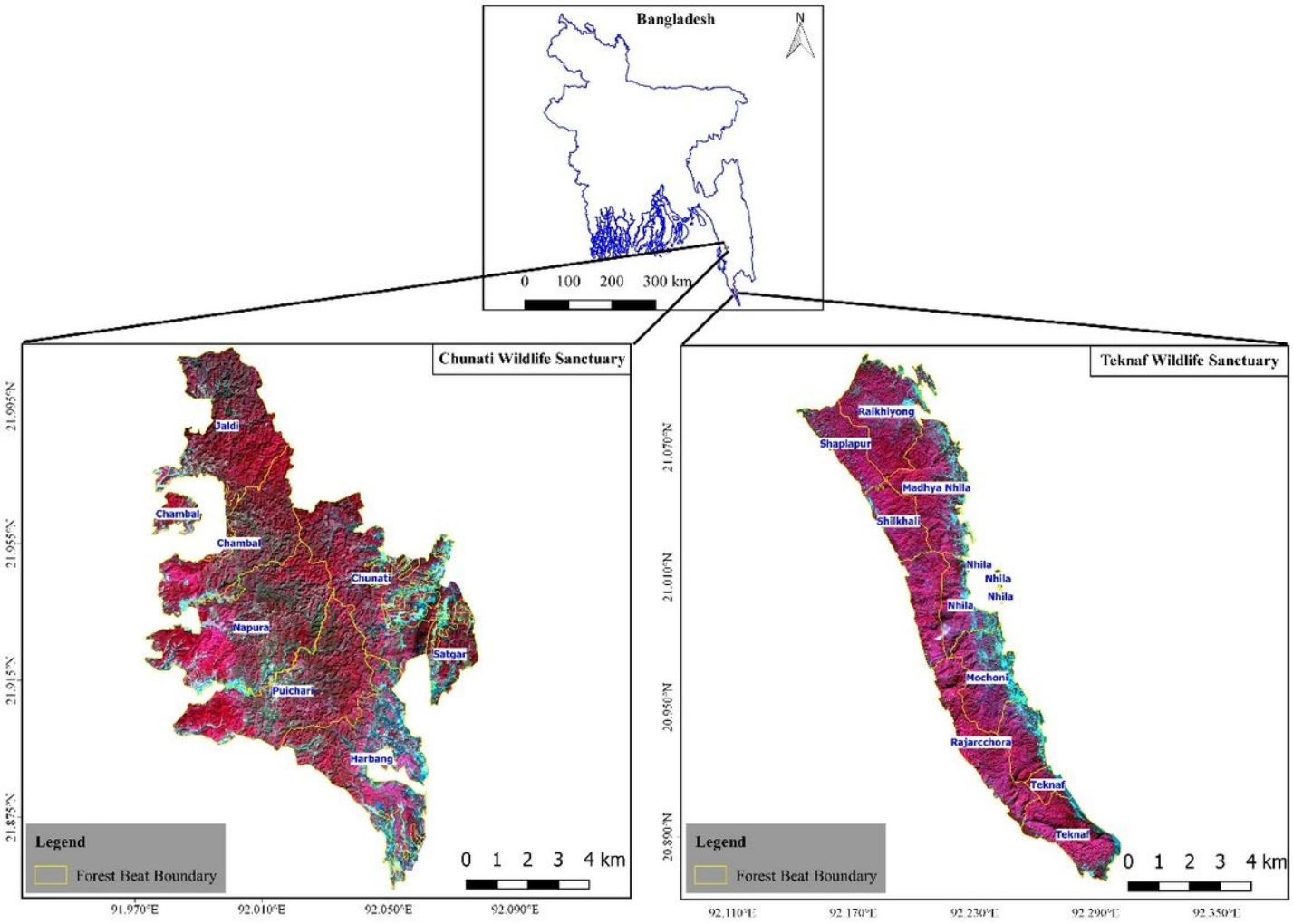

Figure 1

Location of the study areas in the southeastern region of Bangladesh. False color composite of Chunati and Teknaf wildlife sanctuary extent from Sentinel-2A scene. The map was produced in QGIS environment (QGIS, 2018) and the data for Protected Area boundary was obtained from World Database of Protected Area

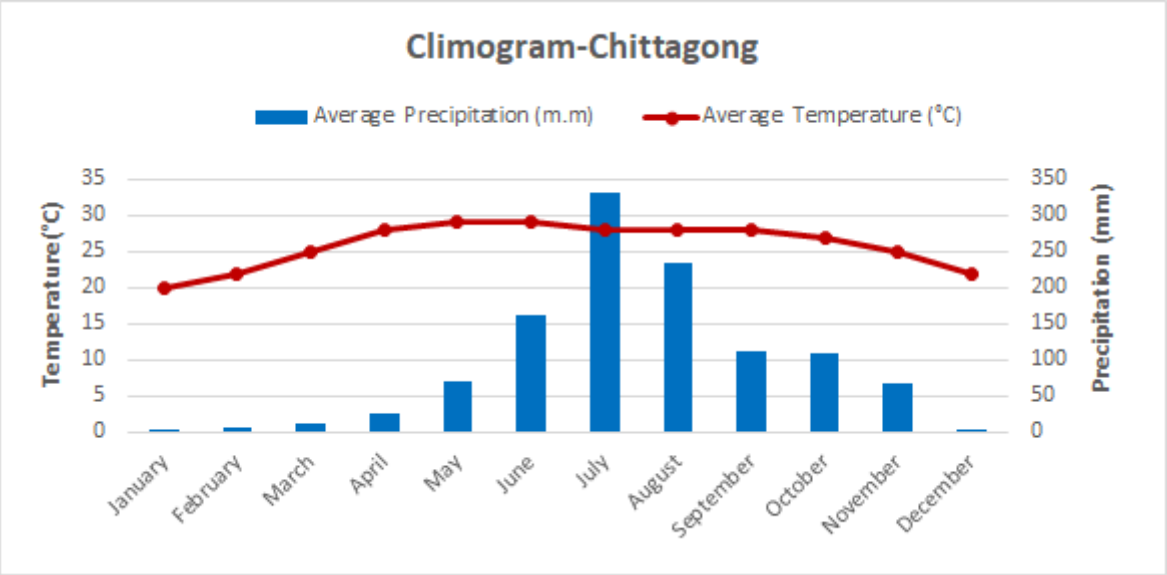

Figure 2

Climograph of the Chittagong Forest Division

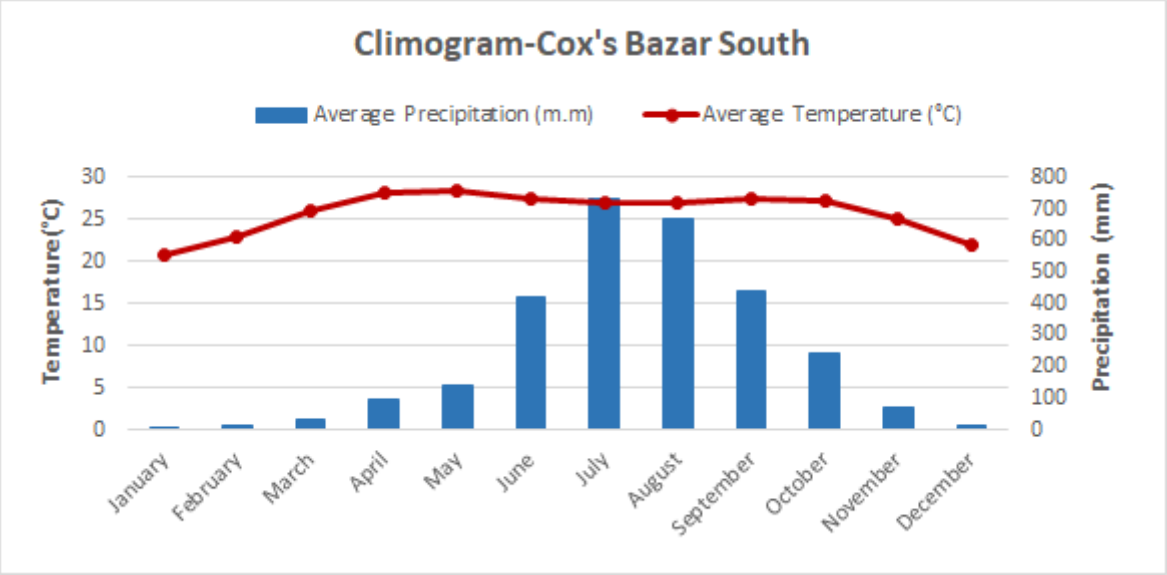

Figure 3

Climograph of the Cox’s Bazar South Forest Division

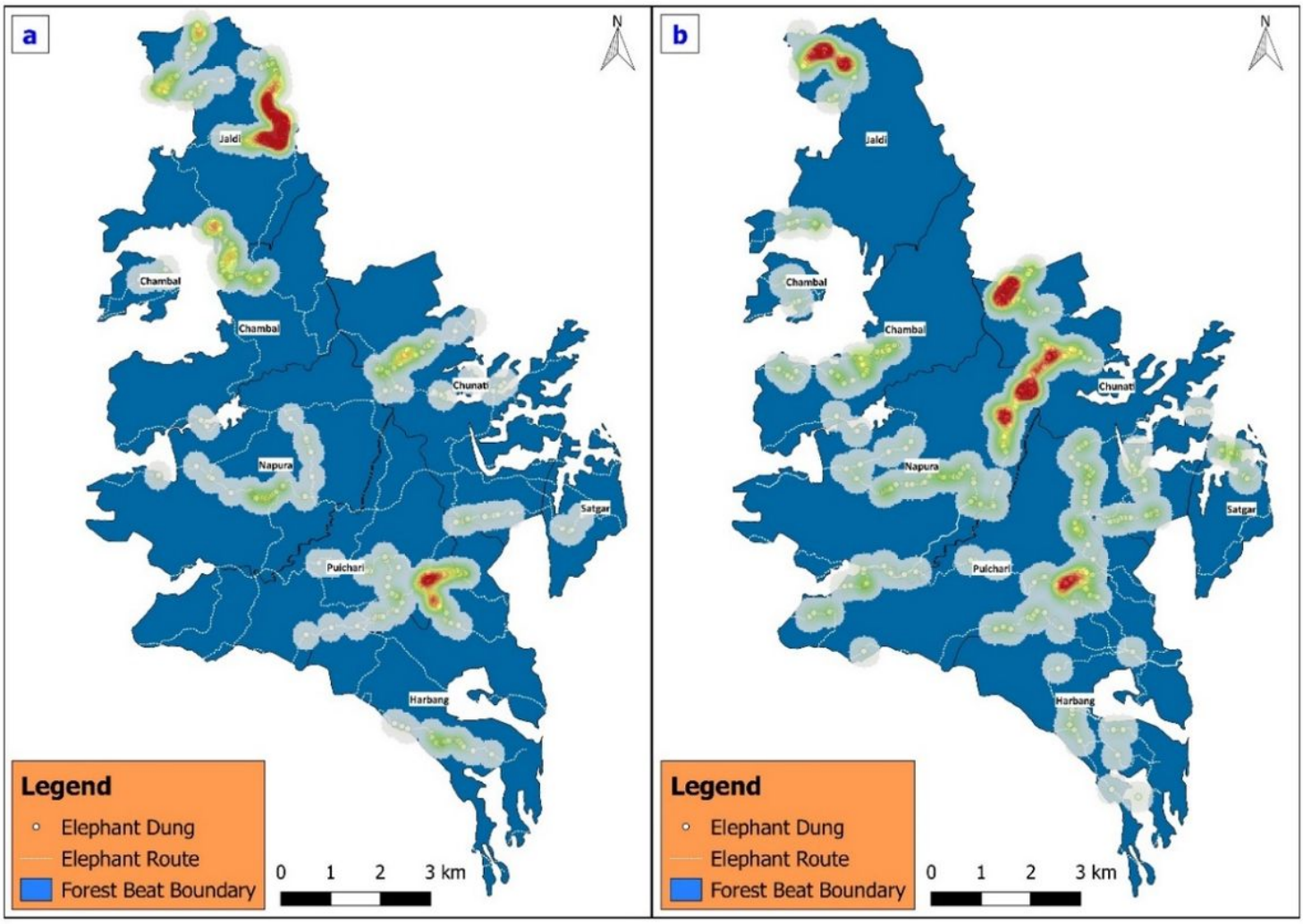

Figure 4

Elephant movement during the a) dry season and b) wet season across forest beats of Chunati Wildlife Sanctuary. Heat Map representing the density distribution of elephant dung where red and green color indicates higher and lower density, respectively

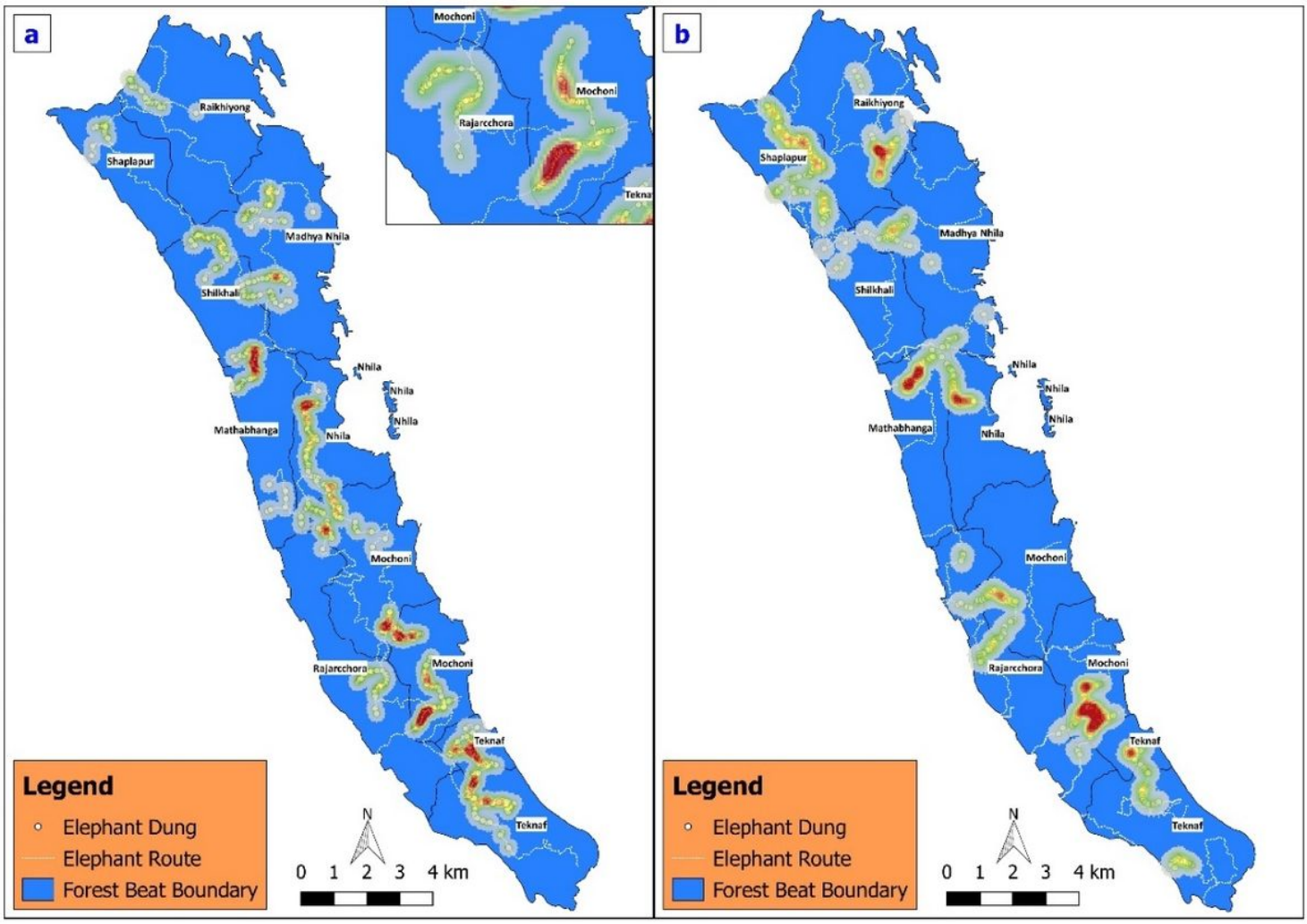

Figure 5

Elephant movement during the a) dry season and b) wet season across forest beats of Teknaf Wildlife Sanctuary. Heat Map representing the density distribution of elephant dung where red and green color indicates higher and lower density, respectively

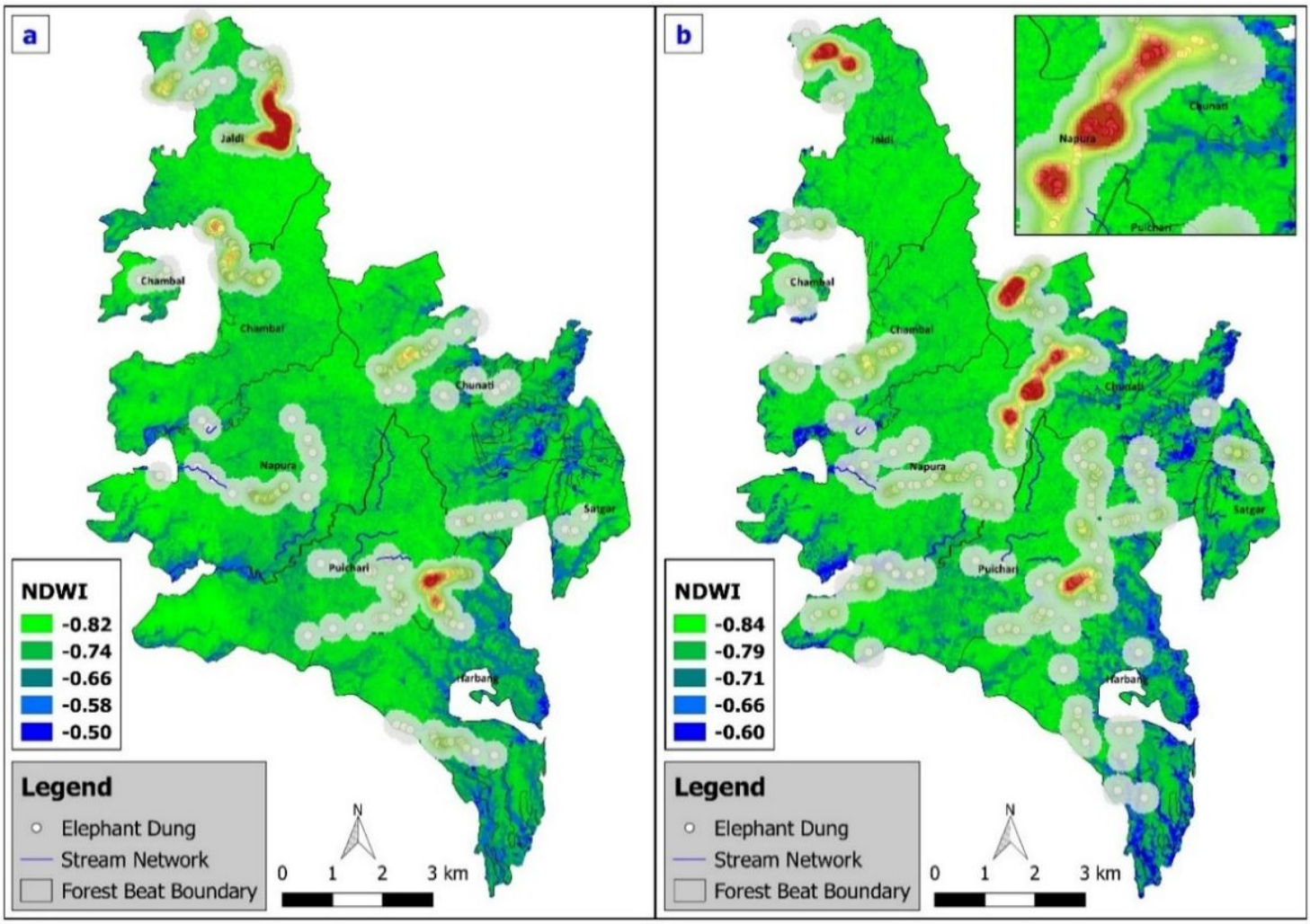

Figure 6

Elephant movement in relation to water resources during a) dry and b) wet season across Chunati Wildlife Sanctuary. NDWI raster image was used as underlying layer

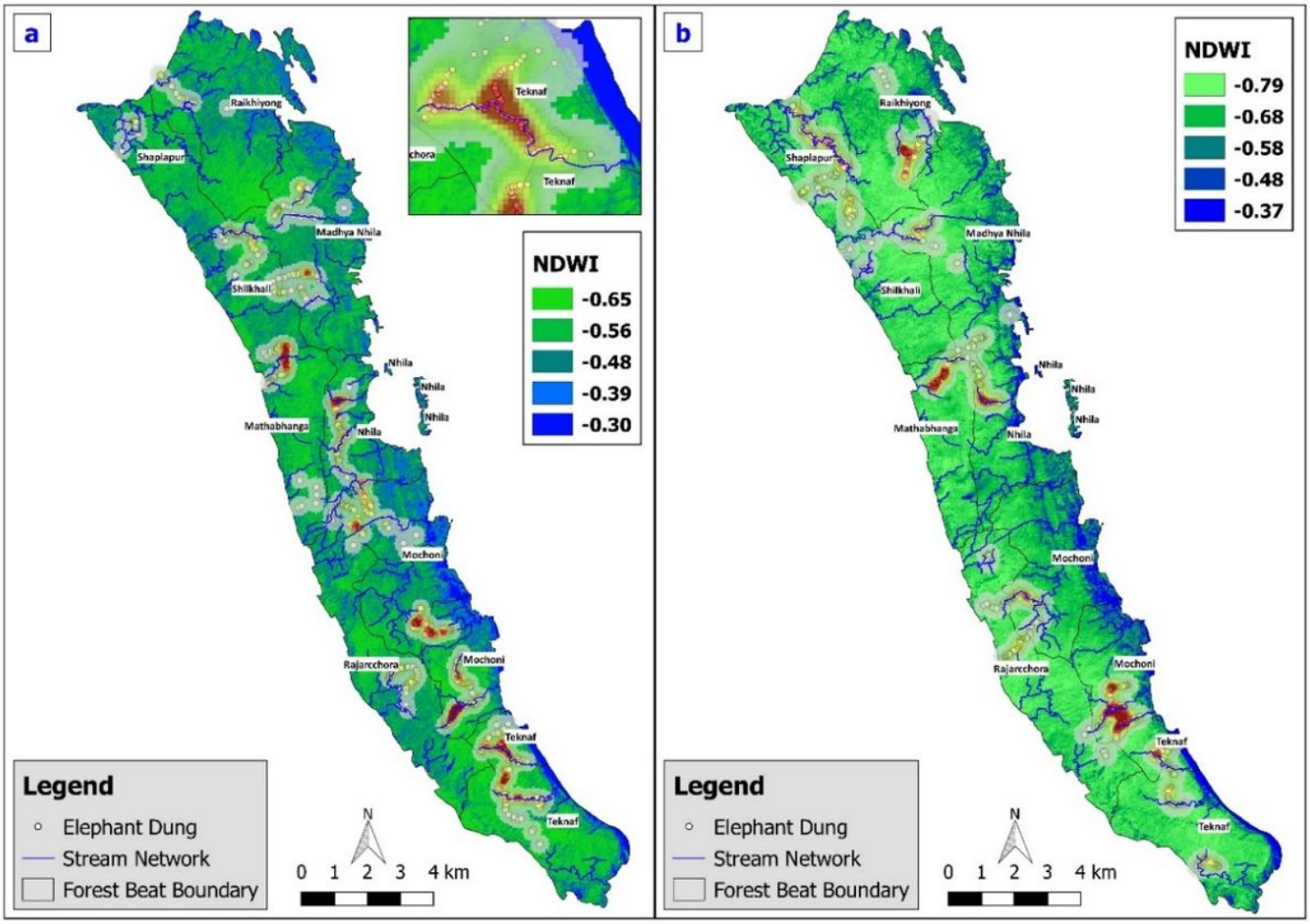

Figure 7

Elephant movement in relation to water resources during a) dry and b) wet season across Teknaf Wildlife Sanctuary. NDWI raster image was used as underlying layer

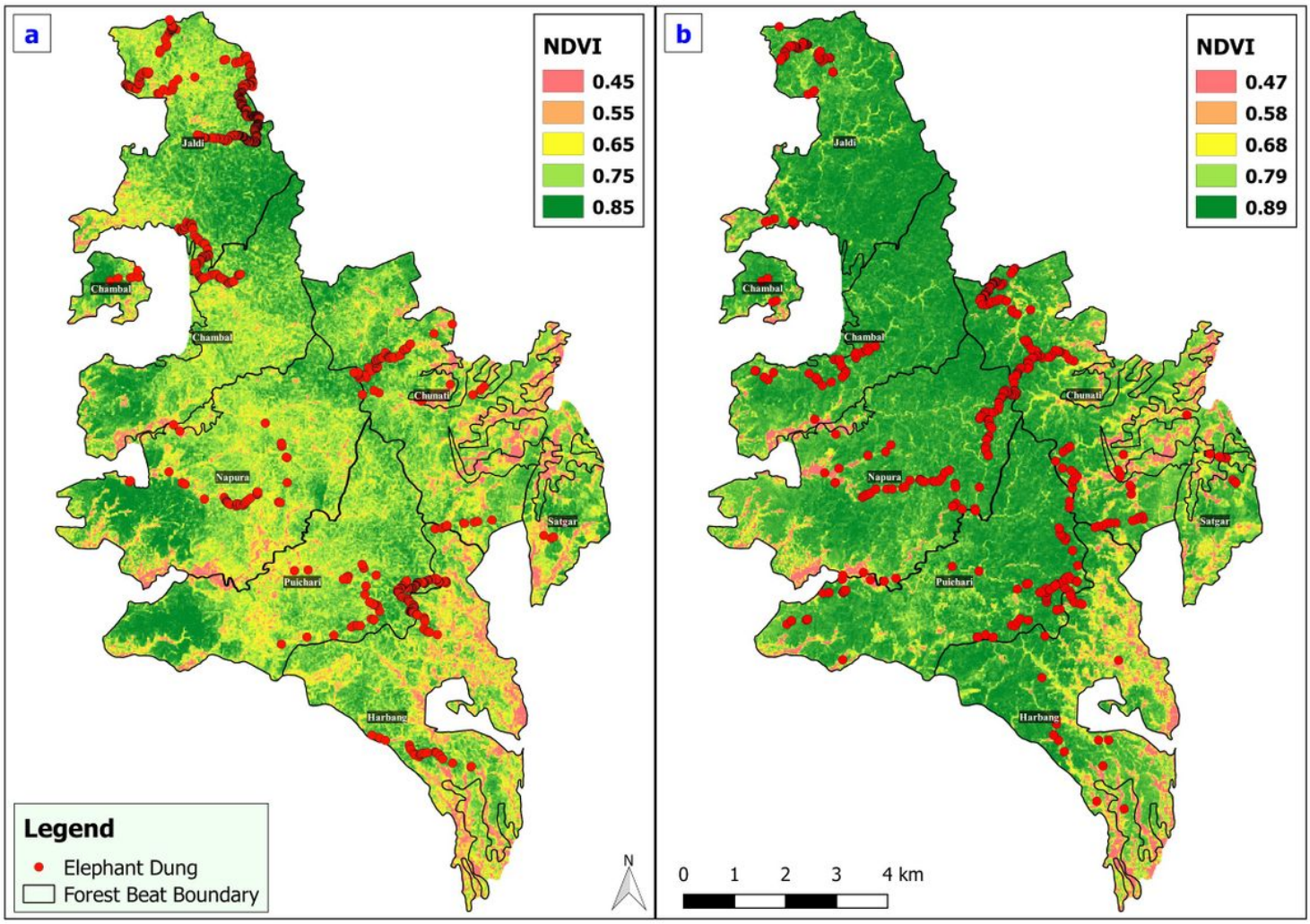

Figure 8

Elephant movement overlaid on a NDVI map during the a) dry season and b) wet season across Chunati wildlife sanctuary

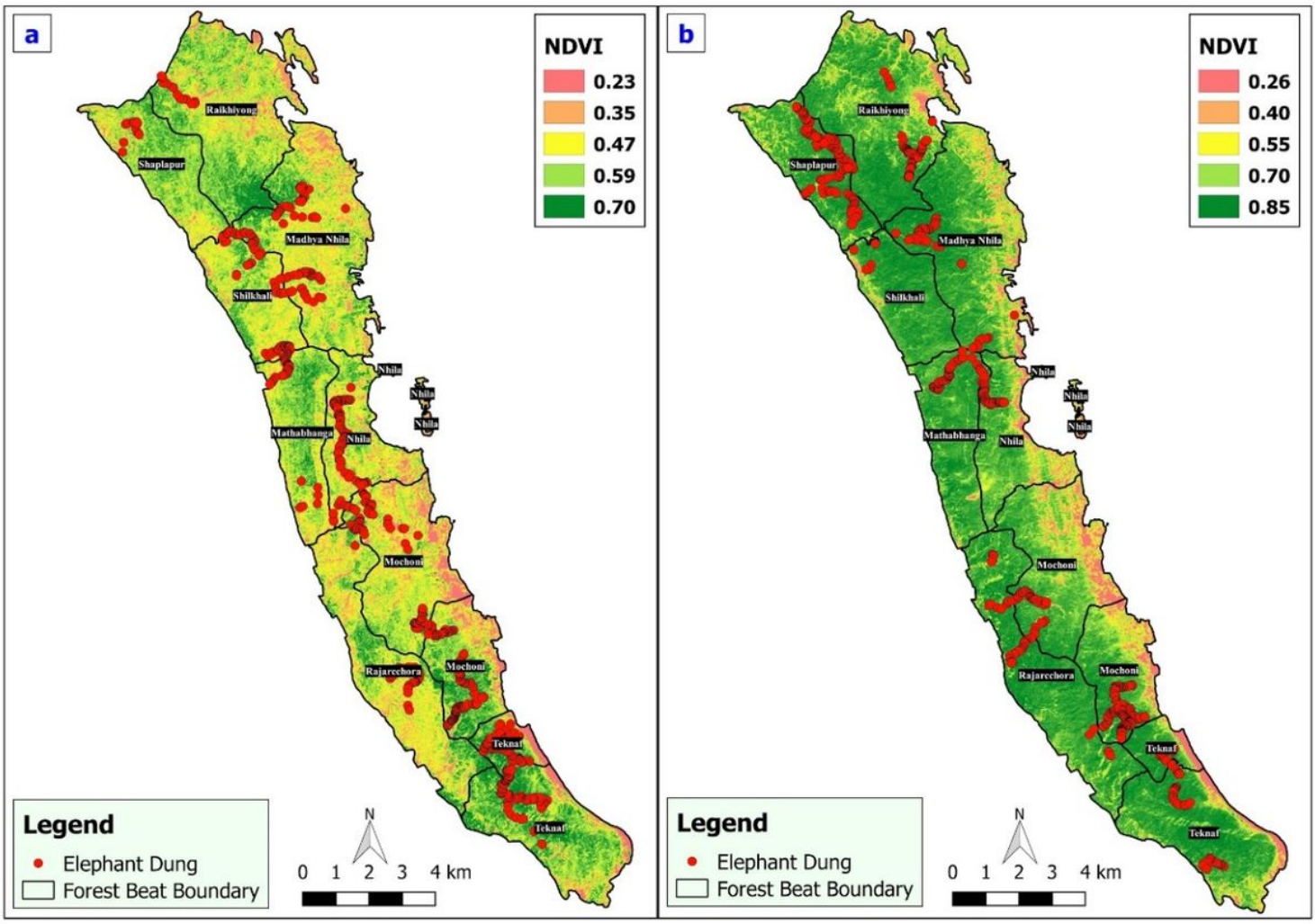

Figure 9

Elephant movement overlaid on a NDVI map during the a) dry season and b) wet season across Teknaf Wildlife Sanctuary